CHAPTER 6: SHIPMENTS ANALYSIS

6.1 INTRODUCTION

Central air conditioner and heat pump (CAC-HP) shipment estimates are a necessary input for national energy savings calculations.

In this chapter we describe an accounting model for projecting annual CAC-HP shipments that accounts for:

- Combined effects of price, operating cost, and income on annual U.S. shipments.
- Market segments (e.g., new housing, replacement decisions, and non-owners adding a CAC-HP).
- Decisions to repair rather than replace.
- Age categories of CAC-HP.

All calculations are performed on a series of Microsoft Excel spreadsheets which are accessible over the Internet. The shipments model is incorporated into a larger spreadsheet model that forecasts national energy savings and net present value. Access to and basic instructions for the spreadsheets are discussed in Chapter 7 on the National Energy Savings and Net Present Value Analysis.

6.1.1 Definition of Market Segments and Ownership Categories

The CAC-HP shipments model described herein segments both CAC-HP owners and CAC-HP purchases into different categories. The different types of CAC-HP owners (e.g. new housing, regular CAC-HP owners, and non-owners) are faced with different types of CAC-HP purchase decisions and purchase motivations. On the other hand, the different CAC-HP purchasers are motivated to purchase a CAC-HP for different reasons. Because of these differences within households and the CAC-HP market, we segment both markets and ownership into different categories. To the extent a model can portray the different behaviors and stock flows of the different market segments, the better it portrays the reality of the CAC-HP market. Additionally, by disaggregating the market and utilizing specific known features of the different market segments, the behavior of the model is constrained to match real market conditions and is more likely to behave in ways consistent with actual market behavior.

As described in Chapter 5, the Life-Cycle Cost and Payback Period Analysis acounts for the use of residential-type central air conditioners and heat pumps in commercial buildings. But for purposes of forecasting shipments, only the residential housing market is considered. Although ignored in the shipments model, commercial applications are accounted for in the National Energy Savings and Net Present Value Analysis by adjusting the annual energy consumption of central air-conditioning and heat pump equipment to reflect their use in commercial buildings. More details on the annual energy consumption adjustment are provided in Chapter 7.

In this shipment forecast model, households with air conditioning equipment are classified into a Central Air-Conditioning (CAC) households and a Heat Pump (HP) households using the relative market share of the different types of equipment. The two types of systems are further classified as split or package systems according to the relative market shares of the system type. The shipment forecast model first calculates the over-all dynamics of the combined CAC-HP market Households in this combined market are further divided into four different ownership categories, while consumer purchases of CAC-HP are divided into five different market segments. The four CAC-HP ownership categories are: 1) new housing, 2) existing housing with a regular CAC-HP, 3) housing without a CAC-HP, and 4) housing with an extended life CAC-HP. We refer to the population of CAC-HP in each ownership category as the ***stock*** of CAC-HP of that category.

Meanwhile the different types of CAC-HP purchases are divided into five separate market segments as follows:

- <u>New Housing Market</u>: When new homes are completed, they will result in the purchase of new CAC-HPs.

- <u>Early (Discretionary) Replacement Market</u>: Even before a CAC-HP breaks down, about 29% of CAC-HP owners replace the existing CAC-HP because they want an updated model, because of remodeling, or for other miscellaneous reasons.

- <u>Regular Replacement Market</u>: Most CAC-HP purchases result from the replacement of an existing CAC-HP that has broken down after the completion of its useful life.

- <u>Extra Repair Market</u>: Under conditions of high costs for new CAC-HP a few consumers will rebuild or repair a broken down CAC-HP (thus extending its lifetime) rather than purchasing a new CAC-HP. Eventually, even extended life CAC-HPs breakdown and are replaced.

- <u>Remodeling Market</u>: When people change residence or remodel their homes they may install new air conditioning equipment.

The ownership categories reflect the *type* of CAC-HP that a consumer has, while the markets segments reflect the *reasons* for purchasing a new CAC-HP.

The CAC-HP Shipments Model keeps track of the population of each type of CAC-HP and CAC-HP purchase. Events and consumer decisions influence how the stock and supply of CAC-HP flow from one category to another. Decisions which are economically influenced are modeled with econometric equations.

Figure 6.1 shows the detailed flow diagram for the CAC-HP Shipments Model.

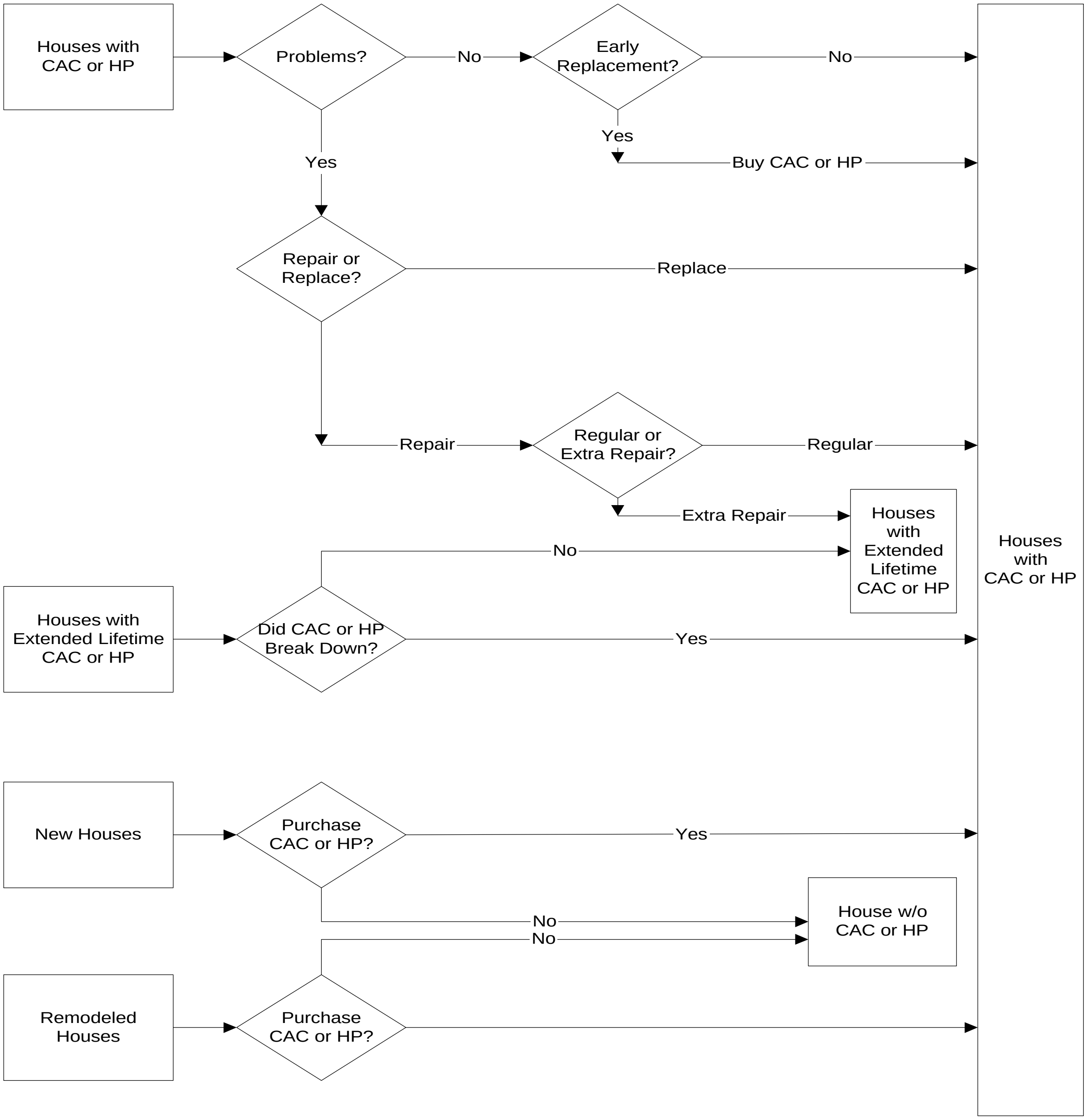

Figure 6.1 Flow Diagram for CAC/HP Shipments Model

As depicted in Figure 6.1, households are faced with a series of decisions of whether or not the current unit will be replaced, or whether a new unit will be purchased. The types of households are illustrated with rectangles, and the decisions to which the households are subjected are indicated by the arrows. Each branch of a decision or event tree is illustrated with a diamond which has one input arrow, and two output arrows. The decisions to which each category of households (and their CAC-HP unit) are subjected are described below:

New households are those households which represent a net increase in housing stock (new housing construction less housing stock removed from the market). These households are faced with the decision of whether or not to get a new CAC-HP with the house.

For households with existing regular units, the first question is whether or not the current unit is having operational problems (i.e. needs repair). If the unit is without problems then the consumer must decide if he or she wants to purchase a unit for other discretionary reasons. If the unit has operational problems, then the consumer must decide if the unit is to be repaired or replaced. If the consumer makes an extra repair to avoid purchasing a new unit, then the model assumes that the repair extends the unit lifetime by six years.

For households without CAC-HPs a small fraction (at most a few percent) of consumers will decide to become new CAC-HP owners in a given year.

Households with extended lifetime CAC-HPs are those households that have extended the lifetime of their unit through an extra repair when the unit last broke down. When the CAC-HP breaks down yet again, the consumer will have to have it replaced..

In section 6.1.3 we review the economics durables sales forecasting literature; section 6.2 describes the details of the mathematical structure of the model, while section 6.3 discusses the modeling of economic consumer decisions, and section 6.4 presents the model results.

6.1.2 Shipments Model Features

We have incorporated a variety of features in the CAC-HP shipments model in order to provide more detailed predications and accounting the forecasts.

Detailed accounting of different market segments and CAC-HP ownership categories: The model accounts for a variety of market dynamics including changes in repair behavior and extending the life of CAC-HPs through extra repairs.

Purchase price, operating cost, and income elasticities: The model includes consumer responsiveness to purchase price, operating costs, and income. Assumptions about the inter-relation of different economic factors are used to determine the relative importance while over-all sensitivities are calibrated with historical shipments data.

Incorporation of repair rates and early (discretionary) replacements: The current shipments model utilizes data from a study on heat pump service life to establish both CAC-HP repair rates and the proportion of early (discretionary) replacements[1].

The purpose of the model is to provide the best estimates possible for future CAC-HP shipments that are consistent with the recent history of CAC-HP shipments, and with current CAC-HP market structure and consumer preferences.

While we endeavored to include a diverse set of features in the shipments model, there were some features which for the sake of simplicity and accuracy were not included. In particular there we did not include either a fuel switching elasticity nor regional housing shifts. We do however discuss later in this chapter estimates of the relative impacts of these factors and show that they are relatively small.

6.1.3 Review of Other Published Research

We performed a review of recent literature on forecasting purchases of consumer durables in order to evaluate studies regarding price and features sensitivities and their application to long term sales forecast models. We report on eight relevant studies published from 1990 to the present.

In this literature, a standard measure of consumer sensitivity to features of the products and the market is sales *elasticity*. Elasticity is the parameter that relates the relative change in a feature (such as price, *P*) to the relative change in sales. For example:

$$\Delta S/S = \boldsymbol{e} \cdot \Delta P/P \tag{6.1}$$

where Ä*S/S* is the relative change in sales, Ä*P/P* is the relative change in price, and *g* is the elasticity. Elasticities are generally negative numbers ranging from 0 to -3. A product which has an elasticity -2 will experience a 2% drop in sales for a 1% increase in price.

According to the marketing and sales forecasting literature, consumer price response and elasticity varies dramatically depending on the type of trade-offs being made, the time scale over which sales variations are being measured, the type of durable being examined, and the stage of development of the particular durables market in question.

The greatest price sensitivity is observed when consumers are being asked to make trade-offs between price, brand, and features in an unconstrained market where the consumer has the choice of different brands and makes of product. In this context, which is most relevant to marketing decisions, the choice of from whom to buy a product is highly sensitive to the price being charged by that particular manufacturer. Price/features trade-offs are typically applied to set prices for different product classes according to the over-all value that consumers place on other features relative to price[2].

In the long-term sales forecast literature, elasticities are much smaller than those observed in short term sales or product choice applications. This reflects the difference between a long-term perspective (whether to own a CAC-HP) and a short-term one (which unit to purchase and when to buy). Furthermore, durables undergo a time dependent price sensitivity as they go from introduction to acceptance in the overall market[3 4 5]. Research that examines the change in elasticities over time[6] finds that for clothes dryers and appliances that are deemed ‘necessities’ (i.e. have a high market penetration) that ‘elasticities are either constant, not statistically different from zero, or decline toward the later stages of the adoption life cycle’[7]. These results are based on fitting models with elasticity to historical data on shipments and sales of major appliances.

Since the introduction of standards could potentially cause long term structural changes in prices and features, we consider the results from the long term sales forecast literature most relevant to the present CAC-HP shipments modeling effort. It is expected that elasticities will be smaller than what is found when consumers are evaluating brand or features choices.

6.2 METHOD

6.2.1 Definitions

The model is organized in terms of three classes of items: Stocks, Events, and Decisions. These different classes are defined as follows:

6.2.1.1 Stock

A **Stock** is the number of households with a particular CAC-HP of a particular category. The main property of a stock is that it evolves over the course of the year by aging one year and by increasing or decreasing in response to inflows and outflows produced by events and decisions. The four permanent stocks in the model are new households, households with CAC-HPs, the households without CAC-HPs, and households with rebuilt or extended-life CAC-HPs. In addition to the permanent stocks, there are temporary stocks of CAC-HPs in need of repair, repaired CAC-HPs, rebuilt CAC-HPs, and retired CAC-HPs. All of the temporary stocks are allocated to one of the four permanent stocks within the one year computational time step of the model.

6.2.1.2 Events

Events are things that happen to a stock that can change the status of a portion of that stock, but do not depend on economic conditions. Events do not depend on market conditions, but are dependent on the properties of the stock. The main event in the model is CAC-HP problem development or breakdown. For regular CAC-HP, whether or not a unit develops problems that require a repair is an event. For extended-life units, whether the unit suffers from a final breakdown is another event.

6.2.1.3 Decisions

Decisions are consumer reactions to events and market conditions. Decisions are described in terms of probabilities that typically depend on the type of stock, the age of the CAC-HP, the incremental cost of the decision, and market conditions. The probability of two subsequent decisions in the same year is equal to the product of the two individual decision probabilities. The dependence of decision probabilities on price and market conditions is given by an econometric logit equation:

$$\ln\left(\frac{Prob}{1 - Prob}\right) = a + b \cdot \left(\frac{Price - PWF * OS}{Income}\right) \qquad \textbf{(6.2)}$$

where *Prob* is the probability of the decision, and where the right hand side of the equation represents the utility of the decision. The coefficients *b* represents the consumer sensitivity to changes in product life-cycle cost relative to income. The constant term *a* is an offset for the utility which calibrates the utility to the value of the market share in a reference year. *Price* is the purchase price in the current year, while *PWF* is the present worth factor given the consumer market discount rate for savings versus purchase price trade-offs. *OS* is the operating savings relative to a unit of the average efficiency of units sold in1998, and *Income* is the household income.

The details of model calibration and selection of parameters for the consumer decision model are presented in Section 6.3.1.

6.2.2 Purchases from New Housing

6.2.2.1 Definition

Purchases from net new housing are defined as those purchases that arise from a net increase in the total housing stock.

6.2.2.2 Approach

The decision tree shown in Figure 6.2 illustrates the approach taken for modeling new housing purchases.

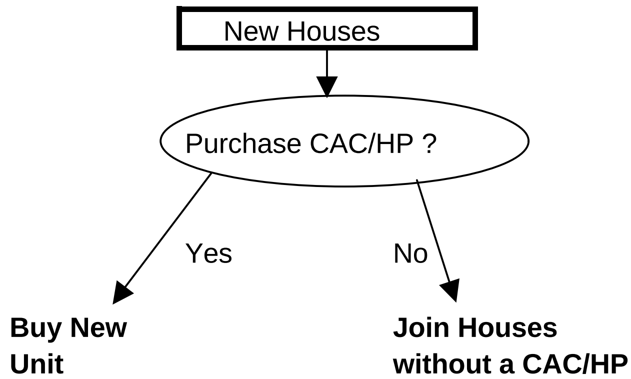

Figure 6.2 Decision Tree for New Housing Purchases

Data is available for the market saturation of new households with CAC-HP units up to 1997 from the Residential Energy Consumption Survey (RECS)[8]. This market share is projected into the future using a logit probability of purchase equation as described in section 6.3.

The equations for estimating the purchases from new housing are as follows:

$$U_{New\,Homes} = EMS \cdot Prob_{New\,Homes} \cdot House_{Completions} \tag{6.3}$$

Where,

$U_{New\,Homes}$ =	New CAC and HP purchases for new home,
$Prob_{New\,Homes}$ =	the probability of purchase of CACs and HPs for new homes,
$House_{Completions}$ =	the housing completions, and
EMS =	the eligible market share for either CAC and HP (this is 90% of all new housing).

For any given year, there are a certain number of CAC and HP systems which are removed during the course of remodels and housing demolitions. Thus, there must be an accounting of the number of CAC-HP units which have been removed from the equipment stock before they have reached the end of their useful life. It is assumed that the number of CAC-HP units removed is equal to the number of housing demolitions multiplied by the current stock saturation of CAC-HP. The equations for estimating housing demolitions and the number of CAC-HP units removed with the demolitions are as follows:

$$House_{Removals} = House_{Completions} + House_{Remodels} - \Delta House_{Stock} \tag{6.4}$$

$$U_{Removals} = House_{Removals} \cdot U_{Stock\,Saturation} \tag{6.5}$$

Where,

$House_{Removals}$ = The net housing stock that is either demolished or has a remodel that would remove an old CAC-HP product,

$House_{Remodels}$ = Housing stock that has a remodel that may remove an old CAC-HP product,

Ä$House_{Stock}$ = change in the housing stock,

$U_{Removals}$ = CAC or HP stock removed with demolished housing stock, and

$U_{Stock\ Saturation}$ = CAC or HP stock saturation.

When the units are removed from the stock, we must assume a particular age distribution. We assume the age distribution is the same as that for replacements, namely:

$$U_{\mathrm{Re}moval}(year, age) = U_{\mathrm{Re}tired}(year, age) \cdot \frac{\sum_{age=1}^{30} U_{\mathrm{Re}moval}}{\sum_{age=1}^{30} U_{\mathrm{Re}tired}} \qquad \textbf{(6.6)}$$

Where,

$U_{Removals}\,(year\ ,age)$ = CAC or HP stock removed with demolished housing stock of a given age in a given year, and

$U_{Retired}\,(year\ ,age)$ = number of CAC or HP units retired of a given age in a given year.

6.2.2.3 Current Assumptions

It is assumed that the relative size of the eligible markets for CAC and HP are in fixed proportion (primarily due to the climate and geography). We used the relative size of CAC and HP market shares in total sales from 1978 to 1997 to determine this ratio[9]. Figure 6.3 shows the market share of heat pumps in air conditioning product sales from 1978 to 1997, and as one can see from the figure, there is no discernable trend, and the level remains at about 23%.

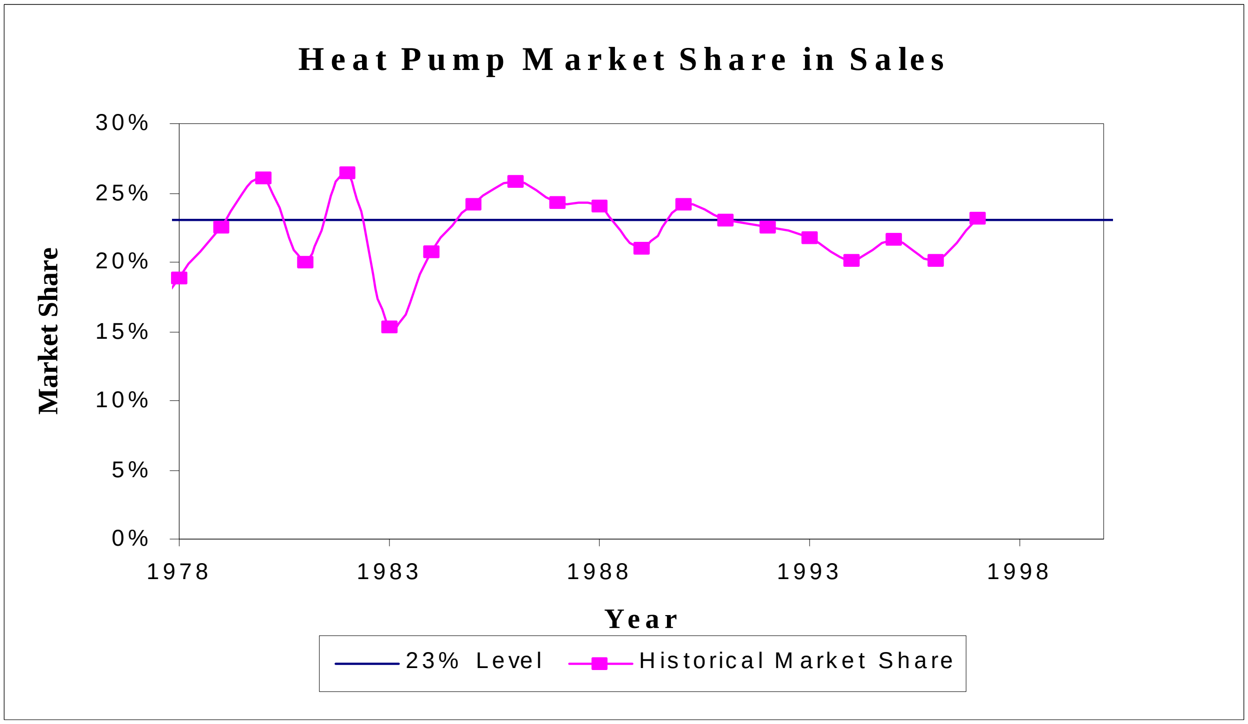

Figure 6.3 Market Share of Heat Pumps relative to Total Central Air Conditioner and Heat Pump Sales

6.2.3 Existing Housing with a Regular CAC-HP

6.2.3.1 Definition

Existing housing with regular CAC-HP are those existing households that have a CAC-HP unit, and whose unit has not had an extra repair that extends the life of the CAC-HP unit.

6.2.3.2 Approach

The decisions involved with the replacement and repair of regular CAC-HPs in existing housing are illustrated in Figure 6.4. The figure shows that several decisions and events affect the replacement of an existing CAC-HP with a new or used machine.

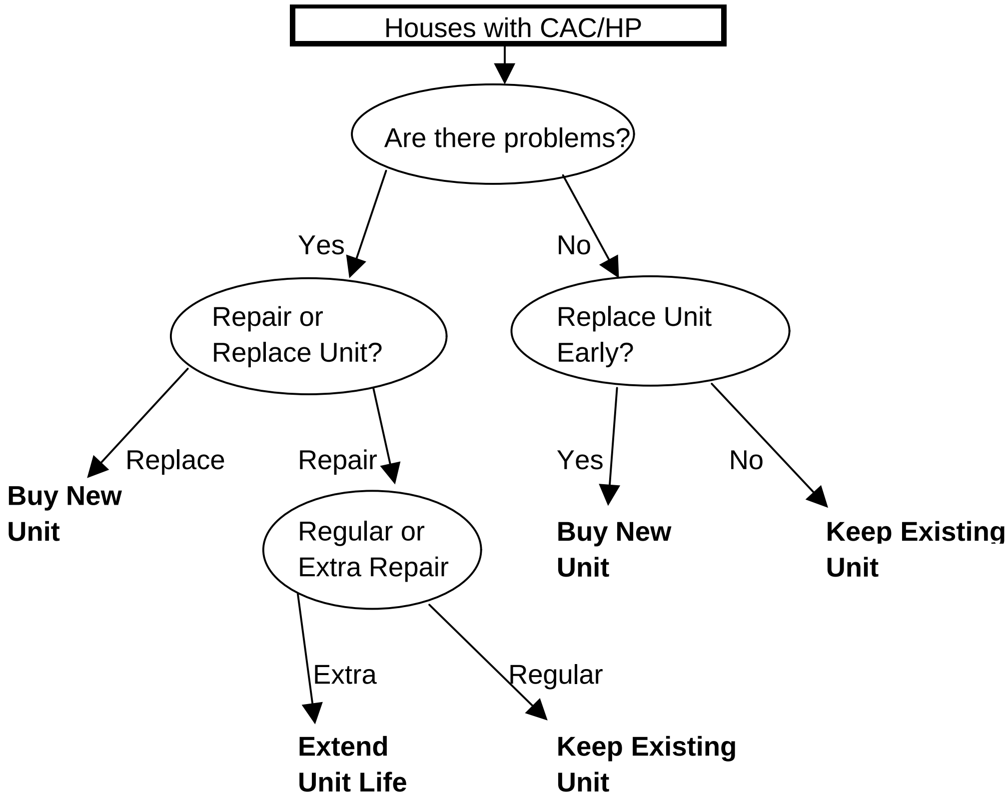

Figure 6.4 Decision Tree for Replacement and Repair of Regular CAC-HP Units in Existing Housing

For a household with an existing CAC-HP unit, the first question is whether or not the unit has problems and needs repair. If the unit needs repair, the consumer will then decide whether to repair the machine or replace it. If the machine is repaired, then the decision is evaluated to see if it is an 'extra' repair for a machine that under normal economic conditions would have been replaced. If it is an extra repair, then the CAC-HP is assumed to have its life extended by six years.

If the machine does not have any problems, the consumer still may replace the CAC-HP early (before breakdown). These discretionary purchases are referred to as *early replacements*. According to a 1987 heat pump survey data[10], about 29% of CAC-HP units are replaced early. Table 6.1 provides the reasons from the survey for why heat pump owners replace their equipment. The percentage of early replacements (29%) are based on all reasons excluding 'Unit Failure' and 'Don't Know/No Answer'.

Table 6.1 Reasons for Replacing Heat Pumps

Reason for Replacement	Percentage of Respondents [a]
Unit Failure	55.6%
Efficiency Upgrade	8.6%
Service Problems	7.9%
Unit Aging	4.6%
Improved Comfort	4.6%
Maintenance Personnel	0.7%
Natural Disaster	0.7%
Advertising/Sales Promotion	0.0%
Other	2.0%
Don't Know/No Answer	47.0%

[a] Multiple responses cause total to exceed 100%.

The decisions and events in the decision tree are modeled with probability functions. We therefore need four relative probability functions to model this purchase decision process:

1. The probability that an existing CAC-HP has a problem.
2. The probability of replacing, or repairing a machine as a function of age.
3. The probability of an early replacement of a machine without problems.
4. The probability that a CAC-HP is not replaced.

1. *The probability that an existing CAC-HP has a problem and needs repair* is based on the same 1987 heat pump survey that is used to estimate early replacements. In the survey, data is presented on the life of the original compressor[11]. For purposes of this analysis, the survival function of the original compressor is used to establish the probability that an existing CAC-HP has a problem and needs repair. Figure 6.5 shows the survival function of the original compressor. It should be noted that the 1987 heat pump survey established a survival function for the original compressor only out to its median lifetime (14.5 years). Linear extrapolation was used to determine the remaining portion of the function.

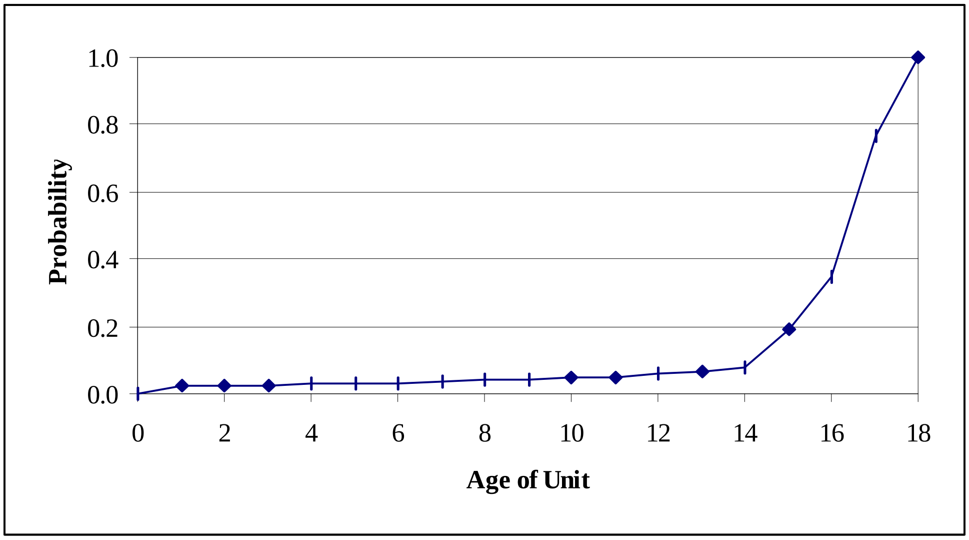

Figure 6.5 Probability Function that an Existing CAC-HP has a Problem

2. *The probability of Repair vs. Replace* (replace and retire are used interchangeably) is subject to market variations and changes as described by a probability of purchase equation:

$$Prob_{Repair\,vs.\,Retire}(year, age) = \frac{Prob_{Needs\,Repair}}{(1 - Prob_{Survival}(year, age))} \qquad \textbf{(6.7)}$$

Where,

Prob$_{Repair\ vs.\ Retire}$ *(year, age)* = Probability of repair vs. retire,
Prob$_{Needs\ Repair}$ = probability of needing repair (as shown in Fig. 6.5) , and
Prob$_{Survival}$ *(year,age)* = probability of survival (as shown in Fig. 6.6).

Again, the 1987 heat pump survey[12] is used to establish the probability of a CAC-HP unit needing repair. The probability of survival is based on the survival function in the 1987 survey for the total heat pump system. Figure 6.6 shows the heat pump survival function. It should be noted that the 1987 heat pump survey established a survival function for the entire heat pump system only out to its median lifetime (19 years). Linear extrapolation was used to determine the remaining portion of the function.

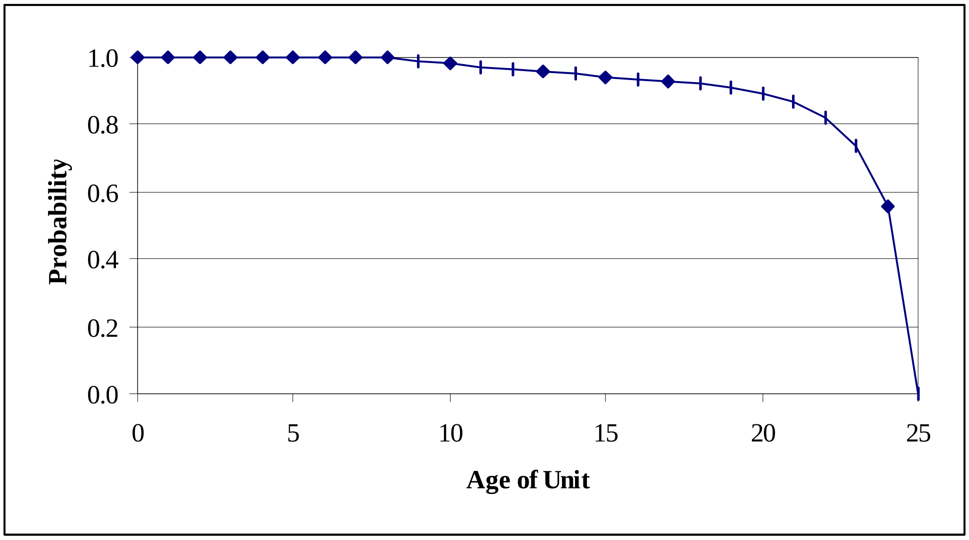

Figure 6.6 Survival Probability Function for CAC-HP Units

The probability that a CAC-HP has a problem and needs repair was presented earlier (Figure 6.5). Thus, as presented in Eqn. 6.7, the probability function for determining whether to repair or replace a CAC-HP units is based on the probability functions for needing repair (Figure 6.5) and survival (Figure 6.6).

If proportionally more machines are being repaired than in the reference year of 1996, then those machines repaired above and beyond the reference level have their life extended by six years. In the model, this is done by moving the machine to the stock of extended lifetime machines, and using a survival probability function for this stock which is shifted by six years.

3. For *the probability of early retirement*, a simple linear function describes the relative probability of a discretionary CAC-HP replacement over time. This function is assumed to be zero at age zero and to increase linearly with CAC-HP age. The slope of this function is chosen so that the relative proportion of discretionary replacements vs. all replacements in the model output is consistent with the 1987 heat pump survey data discussed previously (i.e., 29% is 1987). CAC-HP purchases that result from a change of residence are not considered to be 'replacements'.

Figure 6.7 shows the probabilities for the different decisions and events as a function of CAC-HP age for the model calibration year of 1987. For most of the age of the unit, the most likely disposition of an existing CAC-HP is for it to be kept. There is a significant probability of repairs for much of the machine's life. Meanwhile, as the CAC-HP becomes old the likelihood of replacement becomes dominant. Throughout the units' life, there is some probability of an early replacement. Though in any given year the probability of an early replacement may be small, the cumulative effect of this small probability is approximately 29% of total CAC-HP sales.

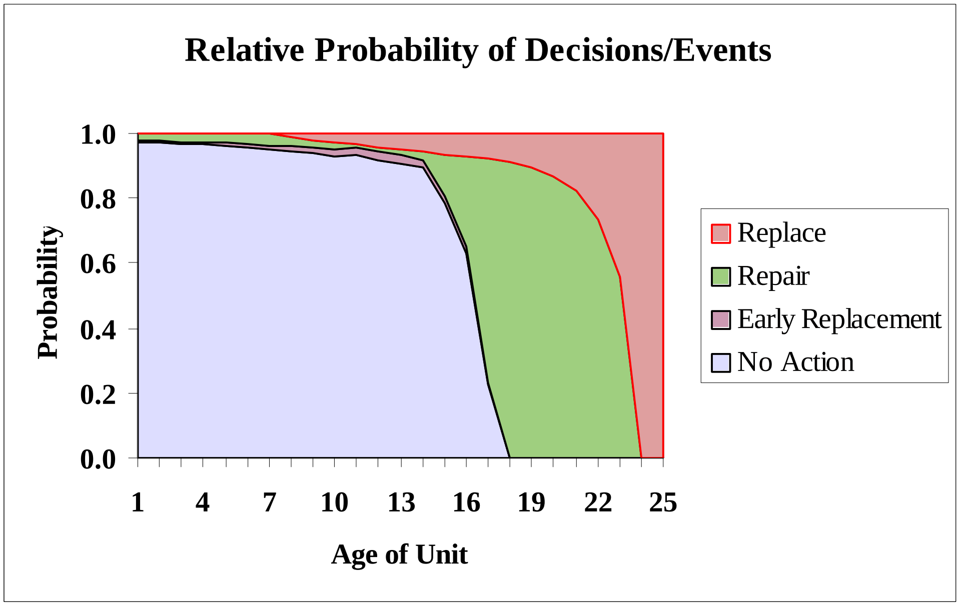

Figure 6.7 Relative Probability of Regular Replacement, Repair, Early Replacement and No Action as a Function of CAC-HP Age for 1987

The equations describing the details of the disposition of the existing units are as follows:

$$U_{Needs\ Repair}(year, age) = Prob_{Needs\ Repair}(year, age) \cdot U_{Stock}(year, age) \quad \textbf{(6.8)}$$

$$U_{Retired}(year, age) = Prob_{Retire\ vs.\ Repair}(year, age) \cdot U_{Needs\ Repair}(year, age) \quad \textbf{(6.9)}$$

$$U_{Early}(year, age) = Prob_{Early}(year, age) \cdot [U_{stock}(year, age) - U_{Needs\,Repair}(year, age)] \quad \textbf{(6.10)}$$

$$\begin{aligned} Prob_{Xtra\,Repairs}(year, age) = {} & Prob_{Retire\,vs.\,Repair}(year, age) \\ & - Prob_{Retire\,vs.\,Repair}(1996, age) \end{aligned} \quad \textbf{(6.11)}$$

$$\begin{aligned} U_{Extra\,Repairs}(year, age) = {} & Prob_{Xtra\,Repairs}(year, age) \cdot U_{Needs\,Repair}(year, age) \\ & (if\ Prob_{Xtra\,Repairs} > 0\ else\ U_{Xtra\,Repairs} = 0) \end{aligned} \quad \textbf{(6.12)}$$

Where,

$U_{Needs\ Repair}(year, age)$ = The number of regular units of a given age that need repairs in a given year,

$Prob_{Needs\ Repair}\ (age)$ =	the probability that a regular CAC-HP unit of a given age needs repair (this function is independent of year),
$U_{Stock}\ (year, age)$ =	the number of regular units of a particular age in a given year,
$U_{Retired}\ (year, age)$ =	the number of regular units retired,
$Prob_{\ Retire\ vs\ Repair}\ (year, age)$ =	the relative probability that a regular CAC-HP which needs repair will be retired,
$U_{Early}\ (year, age)$ =	the number of CAC-HP units that are replaced early,
$Prob_{Early}\ (year, age)$ =	the probability that a CAC-HP will be replaced early,
$Prob_{Xtra\ Repairs}\ (year, age)$ =	the probability that a CAC-HP that needs repair received extra repairs that extended its lifetime, and
$U_{Xtra\ Repairs}\ (year, age)$ =	the number of regular CAC-HPs that received lifetime-extending repairs.

6.2.3.3 Current Assumptions

There are several important assumptions made in modeling the replacement and repair of existing units. These include:

- The needs-repair (or problems) probability function is independent in time. We also assumed that when compressor breaks down is when a unit needs repair. To reiterate, this probability function is based on the survival function of the original compressor as established by the 1987 heat pump survey.

- When a machine breaks down, it is either repaired or replaced.

- All early replacements result in the purchase of a new machine.

- If a greater proportion of machines with problems obtain repairs in the future than they did in 1996, then the additional population of repaired machines have an extended lifetime which is six years greater than the regular CAC-HP lifetime.

- For machines that do not experience problems, the relative probability of an early replacement is zero for a new machine and increases linearly with CAC-HP age.

6.2.4 Remodeled Households

6.2.4.1 Definition

Remodeled households are those households that purchase a new CAC-HP system due to remodeling work.

6.2.4.2 Approach

The approach taken to model purchase decisions by households undergoing remodels that may effect CAC-HP purchases is shown in Figure 6.8. The household has only one decision: whether or not it is going to purchase a unit.

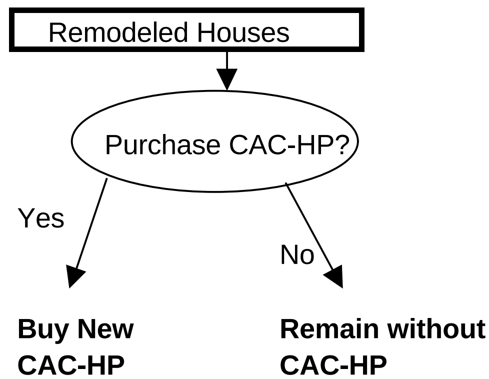

Figure 6.8 Decision Tree for Remodeled Housing

For this, we just assume an annual probability of purchase which varies according to the economic probability of purchase model. We utilize the same purchase probability function used in the new housing market.

The relatively simple dynamics of the decision by a remodeling household deciding to buy a unit is described by one equation:

$$U_{Remodel}(year) = Prob_{New Housing}(year) \cdot House_{Remodel}(year) \quad \textbf{(6.13)}$$

Where,

$U_{Remodel}(year) =$ The number of remodeling households that purchase CAC-HP units in a given year,

$Prob_{New Housing}(year) =$ the probability that a household will purchase a CAC-HP in a given year if it is in the new housing or remodel market, and

$House_{Remodel}(year) =$ the number of remodeling households in a given year.

And the number of remodel households is assumed to be proportional to new housing completions and is therefore described by the following equation:

$$House_{Remodel}(year) = A_{Remodel} \cdot House_{Completions}(year) \quad \textbf{(6.14)}$$

Where,

$A_{Remodel}$ = The coefficient that determines the size of the remodel market relative to housing completions.

6.2.4.3 Current Assumptions

The probability that a remodeling household will purchase a CAC-HP in a given year is assumed to be proportional to the number of housing completions (which measure construction activity), and saturation of CAC-HP in new housing. The over-all size of the market is described by a calibration constant which is set based on data from the Air Conditioning, Heating, and Refrigeration (ACHR) News. For both the CAC and HP markets, the ACHR News estimates that 14% of shipments in 1992 went to the “add-on” market (we assume here that the remodeling market corresponds to the “add-on” market described by the ACHR News)[13]. The 14% value was used as calibration point to estimate the size of the remodel market.

6.2.5 Housing with an Extended-Life CAC-HP

6.2.5.1 Definition

These households have CAC-HP units that have received more repairs than what was normal in the reference year of 1996. It is therefore assumed that the lifetime of these CAC-HPs has been extended by these extra repairs.

6.2.5.2 Approach

The input of this particular stock of CAC-HPs comes from regular CAC-HP households that have made extra repairs on their equipment. Once an extra repair has been made, it is assumed that no more repairs will be made after the next machine breakdown.

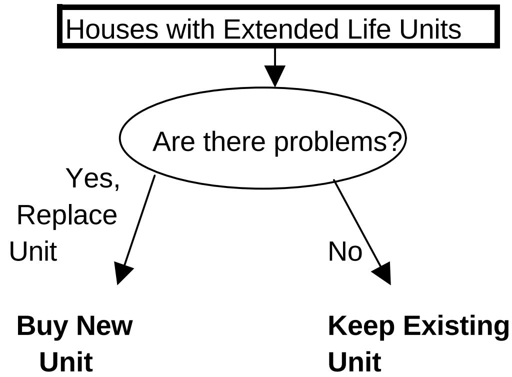

Figure 6.9 Decision Tree for Housing with Extended Life Units

Figure 6.9 illustrates the decision tree for the stock of extended-life CAC-HP units. Note that these CAC-HP units are already quite old because they are regular CAC-HPs that have received extra repairs near breakdown. The main event in this decision tree is whether or not the machine has problems. This probability function is just a shifted version by six years of the survival probability function for regular CAC-HPs and is illustrated in Figure 6.10.

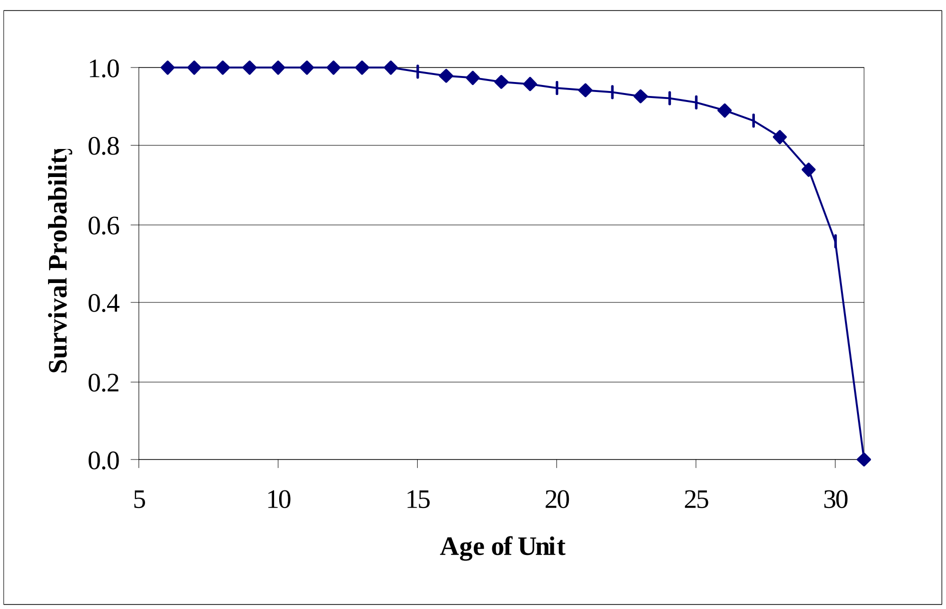

Figure 6.10 Survival probability function for extended life units

In terms of equations, the dynamics of the extended-life CAC-HPs can be described as follows: First the retirement of the CAC-HPs is calculated simply with the retirement (replacement) probability function (shown in Figure 6.10).

$$UXR_{Retired}(year, age) = Prob_{XR\ Retire}(age) \cdot UXR_{Stock}(year, age) \qquad \textbf{(6.15)}$$

Where,

$UXR_{Retired}(year, age)$ =	The number of extended-life CAC-HP units of a particular age retired in a given year,
$Prob_{XR\ Retire}(age)$ =	the probability that an extended-life CAC-HP of a given age will be replaced or retired (based on the extended survival function in Figure 6.10), and
$UXR_{Stock}(year, age)$ =	the number of extended-life CAC-HP units of a given age in a given year.

Then the stock accounting is done such that the change in stock is the number of regular CAC-HPs that get extra repairs minus the stock that is returned:

$$\begin{aligned} UXR_{Stock}(year, age) = {} & UXR_{Stock}(year-1, age-1) - UXR_{Retired}(year-1, age-1) \\ & + U_{Xtra\,Repairs}(year-1, age-1) \end{aligned} \qquad \textbf{(6.16)}$$

Where,

$U_{Xtra\ Repairs}(year, age)$ =	the number of regular CAC-HP units of a particular age that received extra repairs in a given year.

6.2.5.3 Current Assumptions

There are several assumption of the extended-life CAC-HP modeling. These include: 1) Extended life CAC-HPs are never repaired again; 2) The extended-life CAC-HPs have a lifetime that is six years greater than that of the regular units; and 3) The retirement probability function is independent of time.

6.2.6 Accounting Equations

For conducting the shipment forecasts, we specify a series of equations that define the dynamics and accounting of the different types of CAC-HP stocks. For new housing the equation describing the stock of new housing is trivial. The stock of new housing is the number of housing starts.

Meanwhile the most complicated accounting equation is that which describes the accounting of the existing stock of regular CAC-HP units.

For the stock of regular CAC-HP units we have two equations which describe the accounting of the population. The first equation says that the number of one-year old units is simply equal to the number of new CAC-HP units purchased the previous year:

$$U_{stock}(year, age = 1) = U_{New}(year - 1) \tag{6.17}$$

Meanwhile the next equation describes the accounting for CAC-HPs of the different, older age categories:

$$\begin{aligned} U_{Stock}(year, age) = {} & U_{Stock}(year - 1, age - 1) - U_{Retired}(year - 1, age - 1) \\ & - U_{Early}(year - 1, age - 1) - U_{Xtra\,Repairs}(year - 1, age - 1) \\ & - U_{Removals}(year - 1, age - 1) \end{aligned} \tag{6.18}$$

Where,

year =	The year that the stock is being estimated,
U_{Stock} *(year, age)* =	the population of regular CAC-HP in existing housing of a particular age,
U_{New} *(year)* =	the number of CAC-HP purchases in a particular year,
$U_{Retired}$ *(year, age)* =	the number of regular CAC-HP units from a particular age category that were replaced in a given year because of problems that had occurred,
U_{Early} *(year, age)* =	the number of regular CAC-HP units that are replaced early from a particular age category in a given year for discretionary reasons,
U_{Early} *(year)* =	the total number of early replacements (of all age categories) of regular CAC-HP units in a given year,
$U_{Xtra\ Repairs}$ *(year,age)* =	the number of regular CAC-HPs that have received lifetime-extending repairs (these machines get transferred to the extended lifetime stock), and
$U_{Removals}$ *(year,age)* =	the number of CAC-HPs of a particular age that have been removed with the demolished housing stock in a given year.

Eqn. 6.18 indicates that the number of CAC-HP in a particular age category is equal to the number of CAC-HPs in the younger age category of the previous year minus the number of CAC-HP retired or replaced early.

Then for the stock accounting for the extended life machines (those that have received extra repairs), we have the following:

$$\begin{aligned} UXR_{Stock}(year, age) = {} & UXR_{Stock}(year - 1, age - 1) - UXR_{Retired}(year - 1, age - 1) \\ & + U_{Xtra\ Repairs}(year - 1, age - 1) \end{aligned} \tag{6.19}$$

Where,

UXR_{Stock} *(year, age)* = The number of CAC-HP units in a given year of a given age group that belong to the stock of machines that have received extra repairs, These extra repairs have extended the life of the machine,

$UXR_{Retired}(year, age)$ = the number of machines of a particular age that are retired from the extra repair stock in a given year, and

$U_{Xtra\,Repairs}(year, age)$ = the number of regular CAC-HP units of a particular age in a given year that receive repairs that extend the machine life in a given year.

Eqn. 6.19 says that the stock of extended life CAC-HPs comes from regular CAC-HP units which receive extra repairs when they break down. This stock then ages, and is removed as it is retired due to additional repair problems.

Eqn. 6.20 says that number of non-owner households is the number of households minus the number of regular CAC-HP owners minus the number of extended life CAC-HP owners.

The CAC-HP purchase are related to changes in the different CAC-HP stocks as follows:

$$U_{New}(year) = U_{Retired}(year, age) + UXR_{Retired}(year, age) + U_{Early}(year, age) + U_{Remodel}(year) + U_{New-New\,Home}(year) \qquad \textbf{(6.20)}$$

Where,

$U_{New}(year)$ = The number of new CAC-HP purchases in a given year,

$U_{Remodel}(year)$ = the number of CAC-HP units purchased by households undergoing remodeling

In the rest of this report we will describe in more detail how this accounting approach is implemented to forecast CAC-HP shipments.

6.3 MODEL

In order to estimate the impact of standards-induced price and features changes it is necessary to have a model which describes consumer decisions.

6.3.1 Logit Probability of Purchase Model

6.3.1.1 Logit Equation

The mathematical building block for the modeling of consumer decision probabilities is the logit probability of purchase model. In this model, the probability of purchase depends on the utility of the CAC-HP, Util, which depends on the attributes of the appliance. This purchase probability is constrained to be between 0 and 1, and relative changes in the probability of purchase are proportional to changes in the utility of the appliance. These theoretical requirements for the decision probability function can be satisfied by requiring that the probability of purchase function satisfies the following equation:

$$\partial Prob \big/ Prob = \partial Util \cdot (1 - Prob) \qquad \textbf{(6.21)}$$

where *Prob* = decision probability, and $\partial Util$ is the differential change in utility which is a linear function of the CAC-HP attribute variables. The factor of *(1-Prob)* on the right hand side of the equation enforces the condition that the probability of purchase never exceeds 1.

We can solve the above equation for the probability function assuming a particular functional form of the utility in terms of the attribute variables:

$$\partial Util = b \cdot \partial \left(\frac{Price - PWF * OS}{Income} \right) \qquad \textbf{(6.22)}$$

where the differential change in utility is equal to a linear function of differential changes in price, operating savings and features changes. Substituting Eqn. 6.22 in Eqn. 6.21 and then integrating we obtain:

$$ln\left(\frac{Prob}{1 - Prob} \right) = a + b \cdot \left(\frac{Price - PWF * OS}{Income} \right) \qquad \textbf{(6.23)}$$

or

$$Prob = \frac{1}{1 + e^{-\left[a + b \cdot \left((Price - PWF * OS) / Income \right) \right]}} \qquad \textbf{(6.24)}$$

where ***a*** is a constant of integration determined by the values of the probability at initial market conditions. This can also be written as:

$$Prob = \frac{e^{Util}}{1 + e^{Util}} \qquad \textbf{(6.25)}$$

Where,

$$Util = a + b \cdot \left(\frac{Price - PWF * OS}{Income} \right) \qquad \textbf{(6.26)}$$

Thus, the above equations define the logit probability of purchase model.

6.3.2 Determination of Market Shares

In the shipments model for CAC-HP, there are important interactions and constraints imposed by the interaction between different sub-markets. For this reason the CAC-HP shipments model first solves for the sales of all central air conditioning products, and then divides the markets, sales, and stocks between different product types.

Usually, houses get only one central air conditioning system which is either a central air conditioner with gas heating, or a heat pump which provides both cooling and heating services. In addition, central air conditioning systems and heat pump systems come as either split systems or as packaged systems. If all four product types are modeled independently, then it is possible for the total saturations of the systems to exceed one, and an important over-all constraint to sales and stocks may not be satisfied. We therefore first solve for sales of all air conditioning systems, and then divide households and sales between CAC and HP. Then for each of CAC and HP we divide households and sales into split vs. package systems. We also allocate different proportions of sales and stocks to different regions of the country and to commercial buildings so that we can calculate the proper weighted averages of heating and cooling energy use.

6.3.2.1 Eligible Market Share for AC

Some parts of the U.S. do not require any air conditioning, and how cheap they may become central air conditioning systems will not reach 100% saturation. This implies that the eligible market for central air conditioning systems is less than 100%. To estimate the size of the eligible market we do two fits to historical data. One fit is for housing stock saturations over time, while the other is for new housing over time. The eligible market in the housing stock is less than that for new housing because old house designs in some parts of the country may not allow for upgrades to central air conditioning systems. We estimate the size of these eligible markets by fitting a logit market saturation model (with price/income as the primary economic driver for consumer decisions) to the historical saturations. When we do this fit, we find that the best fit value for the housing stock eligible market is approximately 80% while that for new single family housing is approximately 90%. Figure 6.11 shows the logit market saturation model fits to central air conditioning system saturation with 80% and 90% maximum eligible markets for housing stock and new single family housing respectively.

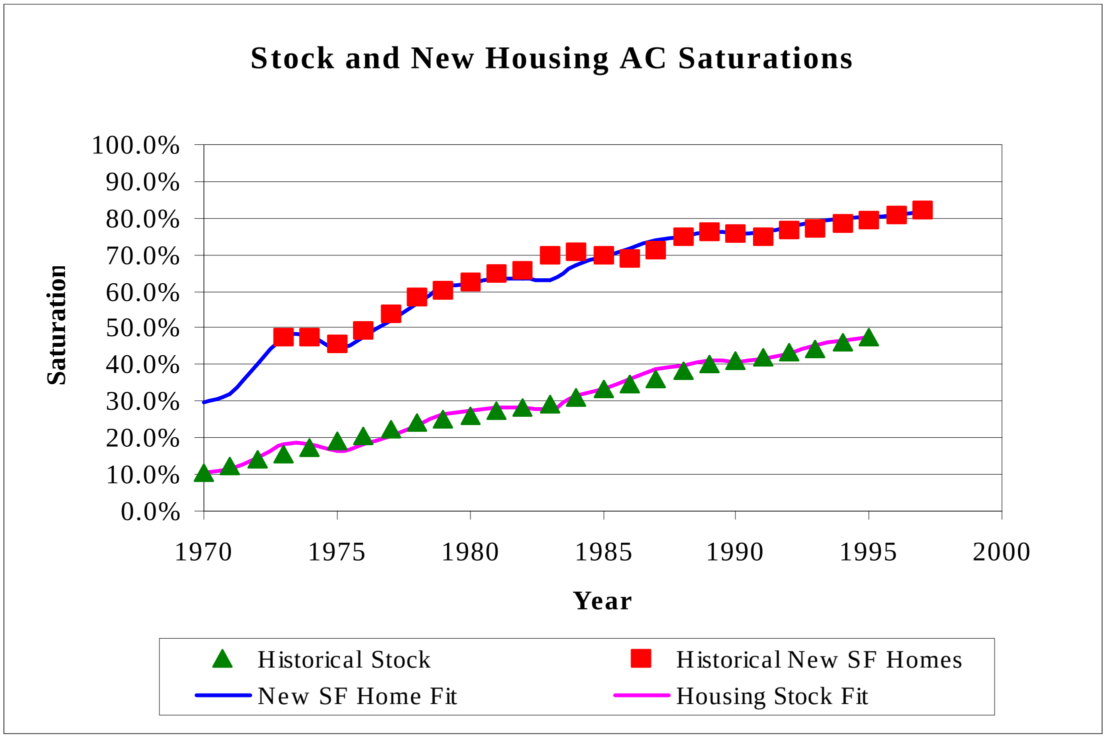

Figure 6.11 Central AC System Saturations in New Single Family Housing and Housing Stock: Comparison of Data and Logit Function Fits

6.3.2.2 Market Share for CAC versus HP

Once the over-all market share for central air conditioning systems is properly modeled, the next task is to divide sales and saturations between simple central air conditioning systems and heat pump systems. During the early stages of introduction of the technology, there was a fairly complex market dynamics between central AC and heat pumps. This is because central AC is a simpler technology that entered the market first and it took some time for heat pumps to attain consumer acceptance and mature as a technology. But referring back to Figure 6.3, after 1978, the relative market share of heat pumps in all central air conditioning systems settled into a reasonably constant value centered around 23%. We therefore use a fixed 23% market share for the size of the heat pump market relative to all central AC products.

6.3.2.3 Market Share of Split vs. Package systems

The detailed dynamics between packaged and split systems sales is largely beyond the scope of the shipments forecast study. We therefore for the sake of modeling simplicity, assumed fixed relative market shares of split vs. package systems for both CAC and HP. The criteria that we used for selecting the relative market shares of split vs. packaged CAC and HP products is that the selected market shares should produce roughly correct shipments values in the late 1990's for packaged system sales. The relative market share values that satisfy this criteria is 88% split versus packaged heat pumps and 90% split versus. packaged CAC. The difference between the optimal values for the model and the relative market shares in currently observed sales comes from the fact that relative market shares of packaged systems are declining over time, and some packaged systems are being replaced with split systems. The mathematical structure of the model assumes that packaged systems are replaced with packaged systems. For the model to capture the declining market share of packaged systems it therefore must use a low value of the packaged system market share for the forecast to compensate for the fact that some of the replacement market is being satisfied by split systems rather than packaged systems.

6.3.2.4 Regional Market Shares

In order to calculate energy use amounts and operating expenses, it is necessary to have an estimate of the regional distribution of the different air conditioning products. We calculate the fraction of products in each of the nine Census divisions utilizing household saturation data from the RECS 1997 survey[14]. We also obtain from RECS the approximate average annual operation of such products (in units of hours at peak load) from the regional average energy use, the regional average efficiency and the mean capacity of such systems.

6.3.3 Price

The CAC-HP shipments model initially calculates shipments and stocks for all central air conditioning products and then divides these into the different product sub-markets according to fixed market shares that assume very low inter-product elasticities. In calculating the price, and operating cost over time, a weighted average of different products is taken to estimate the effective unit price for the CAC-HP market and these unit prices must be projected forward and backward in time with the appropriate price indices. This section describes some of the details of how these price averages and projections are made.

6.3.3.1 Average Price Accounting

For modeling total CAC-HP shipments a weighted average price is used that is the average price for all CAC-HP products over all efficiency levels. The price vs. efficiency model is provided by the Engineering analysis, where those efficiencies less than 10 SEER are assumed to be the same price as 10 SEER. To project prices from 1998 to 1969 the Unitary AC producer price index is used, while the all items consumer price index is used to measure inflation and convert prices to real 1998 dollars. Prices are also averaged for the appropriate efficiency level distribution.

6.3.3.2 Historical Operating Cost Estimates

Because the shipments model is integrated with the National Energy Savings calculation, a detailed calculation of the operating costs and energy use is made. This calculation includes keeping an accounting of energy use that is disaggregated by the nine Census Divisions, and the distribution of efficiency levels for each year of interest. As the spreadsheet model was reaching the computational limits of Microsoft Excel spreadsheets, we did not simultaneously calculate the energy use for all four product classes and take the weighted-average. The operating cost calculations are therefore for the particular product of interest relative to a reference year of 1998.

6.3.3.3 Post-Standard Price Scenarios

To calculate the average price of the CAC-HP units after the standard (and the average energy use), assumptions must be made about the distribution of different efficiency level market shares after a performance standard is implemented. There are three assumptions or *efficiency scenarios* regarding post-standard efficiencies.

The first *efficiency scenario* is what we call the NAECA scenario which is a modification of the roll-up scenario. In the NAECA scenario, the market shares are those of the roll-up scenario except that 6% market share that would be at the standard SEER level is distributed equally amongst the next three higher SEER levels.

The second *efficiency scenario* is what we call the "roll-up" scenario. This is where all of the market shares for SEER levels above the standard stay the same both pre- and post-standard, but the market share at the standard level is the sum of the current market shares for all of those efficiencies less than or equal to the standard SEER level.

The third *efficiency scenario* is what we call the "shift" scenario where the relative distribution of efficiencies stays the same, but the market shares for the different efficiencies simply shift with the standard. For example if the standard is a SEER 12 standard, this is two SEER levels higher than the current 10 SEER standard and the market shares for the different SEER levels shift up two SEER levels. For example the market share for the 12 SEER level would be what the current market share for the 10 SEER level is, and the market share for the 13 SEER level post-standard would be the market share for the current 11 SEER level., etc.

These three *efficiency scenarios* allow us to examine the sensitivity of the results regarding the details of the post-standard efficiency distribution. The shift scenario represents the high price and high efficiency post-standard efficiency distribution, the roll-up represents the lower price and lower efficiency scenario, and the NAECA scenario represents a medium case. These efficiency scenarios are discussed in greater detail in Chapter 7.

6.3.4 Model Calibration

There are several parameters that require calibration in the CAC-HP shipments model. These include the amplitude of the early replacement function, the size of the remodel market, the relative importance of savings and price in the consumer decision model, and the over-all sensitivity of purchases to price/income. In addition we examine the question of whether or not there is a measurable fuel switching elasticity and whether regional housing shift effects are significant.

6.3.4.1 Remodels and Early Replacements

In the shipments model we model purchases due to remodels as a market that is correlated to the new housing market, and we describe the size of this market with a single coefficient that determines the size of the eligible remodel market relative to new housing completions. From the Air Conditioning, Heating, and Refrigeration News, we have a relatively recent estimate of the remodel market as 14% of all sales[15]. We therefore set the coefficient of the remodel market size by the condition that the amount of remodel market sales between 1990 and 1996 average approximately 14%. After we make this adjustment and tune other parameters in the model, the exact value may drift slightly but it remains between 13% and 15%.

For the early replacement market, an ASHRAE paper reports that approximately 29% of total sales are early replacements in 1987[16]. We therefore set the amplitude of the early replacement probability function to replicate this figure in the model results.

6.3.4.2 Market Discount Rate

The market discount rate is a quantitative description of how consumers trade off purchase price and operating savings in their purchase decisions. We do not have concrete, precise data on the market discount rate for consumer decisions for air conditioning products. The one piece of information that we have is that more than 75% of consumers in today's market purchase units at minimum efficiency, and that this implies that the implicit consumer discount rate for consumer decisions is fairly large. We assume a discount rate for consumer decisions half way between a one and two year payback which corresponds to 75%. The shipments forecast is relatively insensitive to the precise value of this discount rate. Changing it from 75% to 25% changes the sales forecast for a 12 SEER standard less than 1%.

6.3.4.3 Price/Income Elasticity

After the implicit discount rate for consumer decisions is set, the effective price of the appliance is calculated as *Price - PWF * OS*, where *Price* is the purchase price, *PWF* is the present worth factor corresponding to the discount rate, and *OS* is the annual operating savings relative to a baseline operating cost obtained from the 1997 shipment-weighted efficiency. We then scale this by dividing by average household income and use the effective price divided by income as the primary driver for economic decisions. As described above, there is a coefficient that determines the sensitivity of consumer decisions with respect to this parameter. We assume that the coefficient in the logit decision model is the same in all markets (new housing, remodels, replacements, and early replacements), and we calibrate this last coefficient by minimizing the root mean square (RMS) deviation between the shipments model estimates and the historical shipments data for all central conditioning products between 1970 and 1996.

6.3.4.4 Evaluation of Fuel Switching Elasticity

Measurement of a fuel switching elasticity requires some data which shows a correlation between price differences and changes in market share. But as Figure 6.3 shows, the relative market share of heat pump in central air conditioning sales has stayed relatively constant over the past 20 years. In addition we have little data on the relative prices of heat pumps versus a combination central air conditioner/gas furnace system. There has been some changes in the relative price of gas and electricity as fuels, with the peak of gas prices relative to electricity being in 1983. But there is no corresponding peak in heat pump market share at this time. We therefore conclude that there is no measurable fuel switching elasticity, and we set the fuel switching elasticity to zero in the model.

6.3.4.5 Regional Shift Effects

In this section we provide a brief sensitivity analysis of the size of regional housing shift effects on the shipments results. To estimate the size of possible regional shifts we can compare the the relative market share of housing stock in the four Census divisions between 1980 and 1990. We find that the market share of households in the Northeast decreased from 21.7% to 20.5%, that Midwest household market share decreased from 25.9% to 24.2%, that Southern household market share increased from 32.9% to 34.6%, and Western household market share increased from 19.3% to 20.6%[17]. From these statistics it seems that there is a slow long term shift from the Northeast and Midwest to the South and West. To the extent the shifts are to the Pacific division of the Western region, such housing shifts do not increase energy use, but to the extent the shifts are to the South, this may imply a greater number of average cooling hours for systems sold in the future. To calculate the size of the potential impact, we take 2% of the Northeast market share of central air conditioners for the Mid Atlantic Census division and shift this market share to the West South Central Census division and calculate how much of an impact this has on energy savings from a 12 SEER standard for Split Air Conditioners. Without this market share shift, the energy saved from a standard is 2.31 quadrillion Btu, while with the regional shift the savings is 2.35 quadrillion BTU, less than a 2% change in energy savings. This probably over-estimates the change in energy savings since our calculation is for a fixed housing market shift that occurs before the standard comes into effect, rather than a more gradual shift over time. In addition, the West South Central Census division has the highest air conditioner energy use, while the housing shift would be distributed across the three divisions that comprise the Southern Census region.

We therefore conclude that the small impact on energy savings estimates does not justify the computational complication that would be necessary to include a more precise calculation of the gradual housing shifts that may occur over the post-standard evaluation period between 2006 and 2030.

6.4 RESULTS

6.4.1 Trial Standard Levels

Shipments results are generated based on Trial Standard Levels (TSL). The TSLs are based on the following: 1) efficiency levels identified in the supplemental Advance Notice of Proposed Rulemaking (ANOPR) published in November, 1999, 2) the efficiency level identified as the Maximum Technologically Feasible level, and 3) a combination of efficiency levels for different product classes that has potentially positive impacts on consumers and the Nation.

Based on the preliminary analyses performed in the supplemental ANOPR, it was observed that uniform efficiency levels for all product classes ranging from 11 to 13 SEER appeared to result in the greatest economic benefits to both consumers and the Nation. Consequently, it was announced in the supplemental ANOPR to further consider and conduct analyses for 11 SEER,12 SEER, and 13 SEER, for each product class.

In selecting candidate standard levels, the Process Rule requires the consideration of equipment which has the most energy efficient combination of design options. The highest efficiency level that is "technologically feasible" is known as "Max Tech." The Maximum Technologically Feasible level for each product class is assumed to be 18 SEER. As has been noted in Chapters 4 and 5 of this TSD, in conducting the economic analyses for this "Max Tech" standard level, the greatest production cost multiplier data for each product class and efficiency level available was 15 SEER. Extrapolation of 15 SEER data to 18 SEER was believed to be unjustified. Consequently, the economic analyses for the 18 SEER case are all based on the 15 SEER cost multipliers, therefore, the economic results represent, at best, a lower bound to the actual values.

In addition to considering equipment which has the most energy efficient combination of design options, other criteria for selecting candidate standard levels include: the combination of design options with the lowest life-cycle costs; and standard levels that incorporate noteworthy technologies or fill in large gaps between efficiency levels of other candidate standards levels. In this case the LCC results for different product classes show positive savings for consumers (although not necessarily the minimum savings) and fill in the gap between uniform efficiency levels for the candidate standard levels.

Based on these criteria, shipments results are presented for the following five TSLs:

- **TSL 1**: 11 SEER for all product classes,
- **TSL 2**: 12 SEER for all product classes,
- **TSL 3**: 12 SEER for air conditioners and 13 SEER for heat pumps,
- **TSL 4**: 13 SEER for all product classes, and
- **TSL 5**: 18 SEER for all product classes.

6.4.2 Shipment Results

The model provides a rather detailed picture of possible standards impacts on purchases, replacement, and repair of CAC-HP. Figures 6.12 through 6.14 show the shipments results for the five TSLs based on ARI cost data, a survival function yielding an 18 year average equipment life, and electricity price forecasts from the *Annual Energy Outlook (AEO) 2000* Reference Case. Three sets of results are provided based on the NAECA (Figure 6.12), Roll-up (Figure 6.13), and Shift (Figure 6.14) *efficiency scenarios*. Historical data points are also provided in each of the Figures to show how closely the shipments models agree with historical data.

Under all *efficiency scenarios* shipments drop in the first year that standards become effective as some consumers forego the purchase of more efficient air conditioners and heat pumps due to their higher purchase price. With progressively higher TSLs, product efficiency and product purchase price increase, resulting in a greater number of consumers foregoing the purchase of more efficient equipment. Forecasted shipments differences are slight between the three *efficiency scenarios*. Because the Roll-up *efficiency scenario* assumes the lowest number of high efficiency units beyond the minimum standard level, forecasted shipments are greatest under this *efficiency scenario* as a smaller number of consumers are foregoing the purchase of new equipment. The Shift *efficiency scenario* assumes the largest number of high efficiency units beyond the minimum standard level and, as a result, this *efficiency scenario* forecasts the fewest shipments. Shipments forecasted under the NAECA *efficiency scenario* fall in between those forecasted under the Roll-up and Shift *efficiency scenarios*.

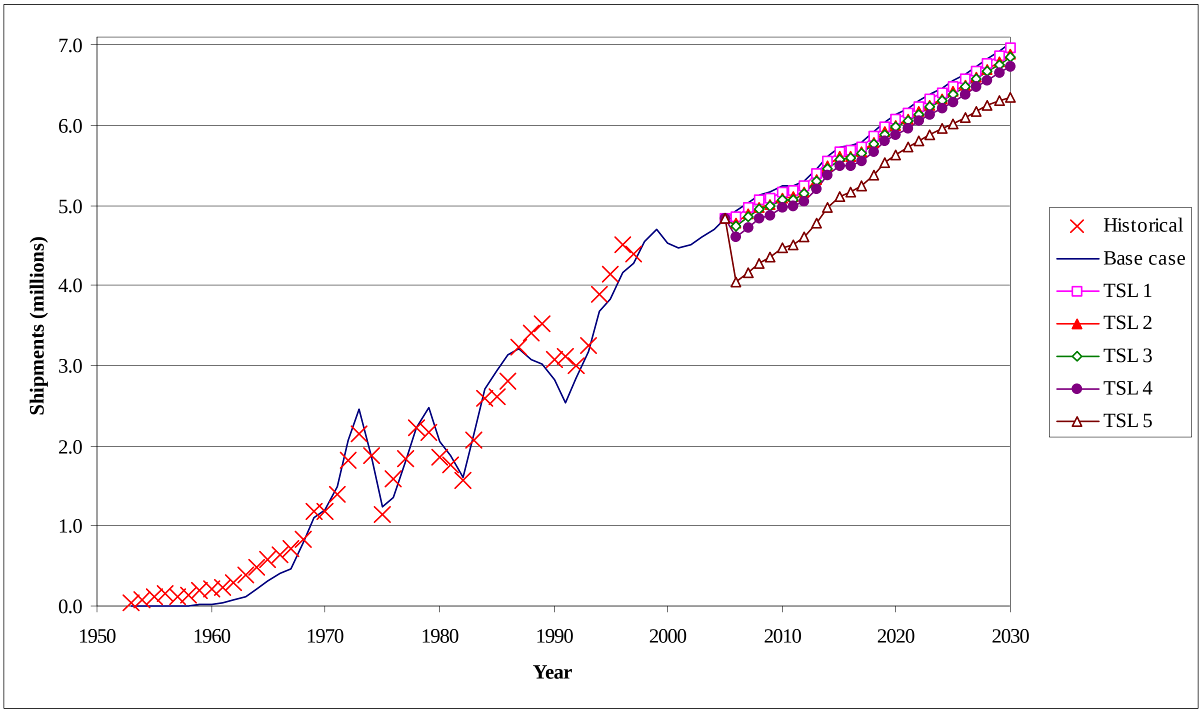

Figure 6.12 Combined Central Air Conditioner and Heat Pump Shipment Forecasts based on NAECA Efficiency Scenario and *AEO2000* Reference Case

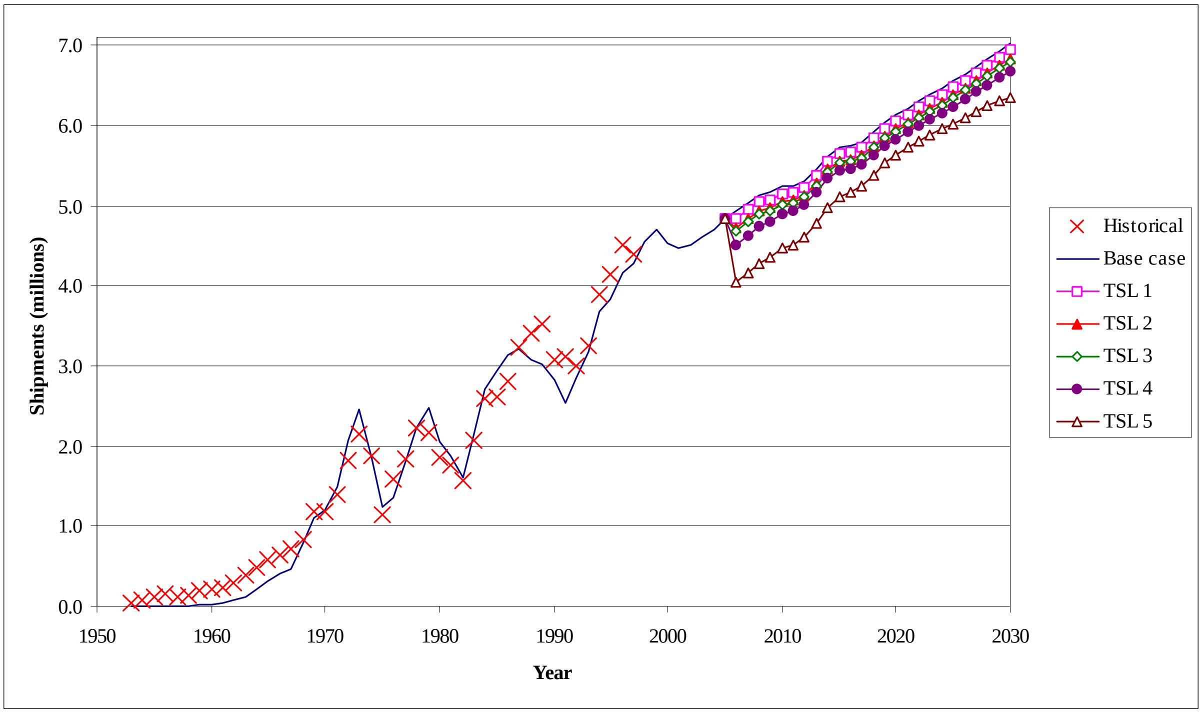

Figure 6.13 Combined Central Air Conditioner and Heat Pump Shipment Forecasts based on Roll-up Efficiency Scenario and *AEO2000* Reference Case

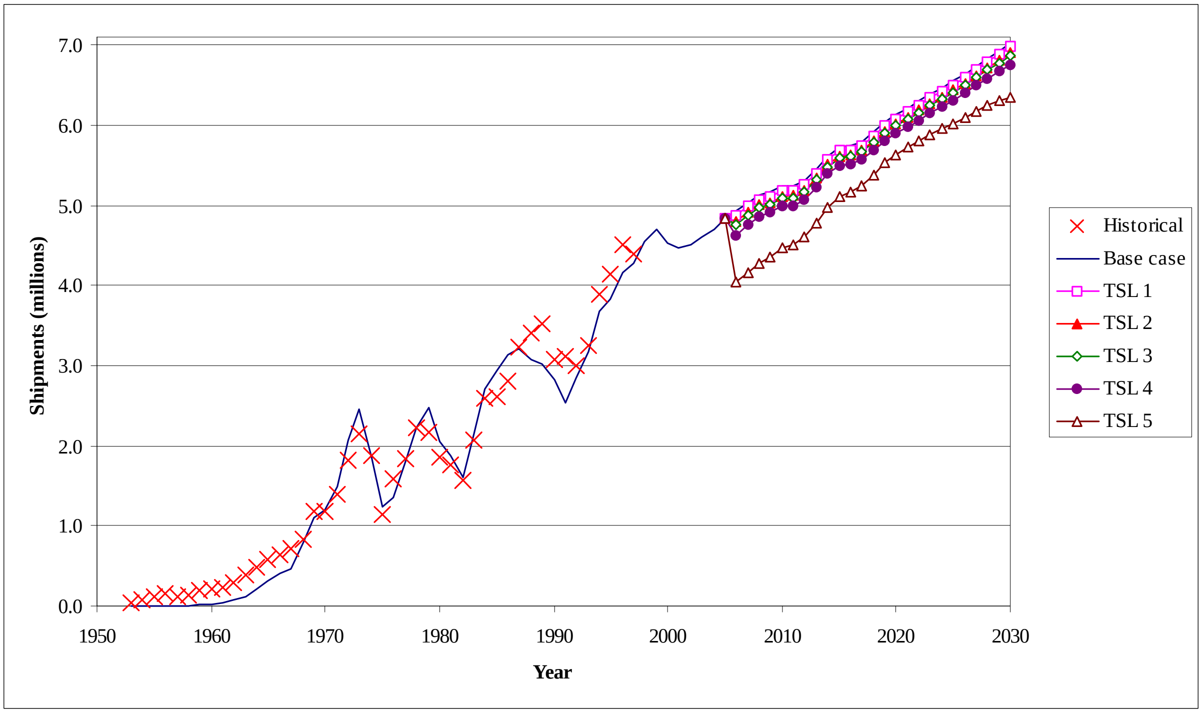

Figure 6.14 Combined Central Air Conditioner and Heat Pump Shipment Forecasts based on Shift Effciency Scenario and *AEO 2000* Reference Case

6.4.2.1 Sensitivity to *AEO2000* Forecasts

Sensitivities were conducted on the impact of different *AEO2000* forecasts on the shipment forecasts. Figure 6.15 shows how the base case shipments forecast under the NAECA *efficiency scenario* is impacted by the *AEO2000* Low Growth Case and *AEO2000* High Growth Case. Shipments forecasts based on the Low Growth Case result in lower shipments relative to the Reference Case while the High Growth Case results in greater shipments. The impact of the Low Growth and High Growth Cases on the base case shipments forecasts under the Roll-up and Shift *efficiency scenarios* are relatively the same as that under the NAECA *efficiency scenario*. In turn, the impact of the different *AEO* forecasts on the five TSL forecasts are also similar to the impact on the base case forecast under the NAECA *efficiency scenario*. Also of note in Figure 6.15, the slight dip in forecasted shipments after 1999 is due to a corresponding dip in new housing completions as forecasted by *AEO2000.*

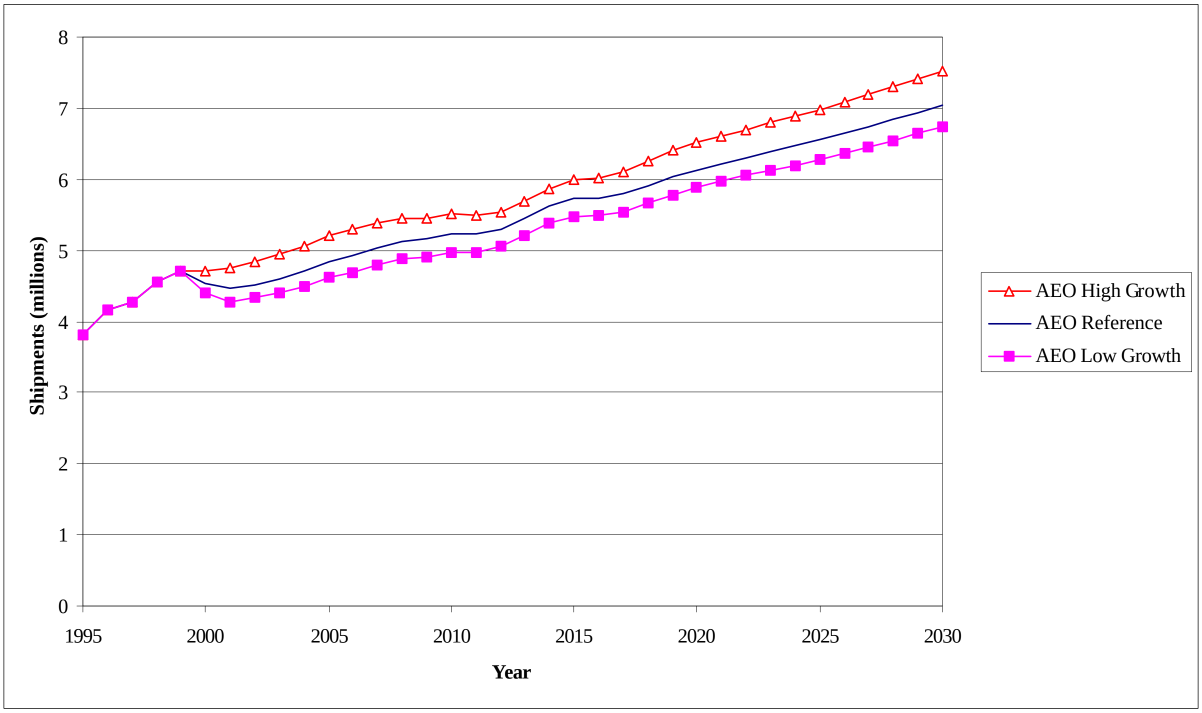

Figure 6.15 Sensitivity of Base Case Shipments, NAECA Efficiency Scenario to *AEO2000* Forecasts

6.4.3 Shipment Scenarios

As discussed in Chapter 5 on the Life-Cycle Cost and Payback Period Analysis, two scenarios were investigated where lower estimates of the manufacturer costs and system lifetime were analyzed. These scenarios are investigated to determine their impact on the shipment forecasts. All shipment scenarios are conducted only with the NEACA *efficiency scenario* and *AEO2000* Reference Case.

6.4.3.1 Manufacturer Cost Scenario

The manufacturer cost scenario involves replacing the cost estimates submitted by ARI with those from the reverse engineering analysis. Table 6.2 shows the percentage change in the annual shipment forecasts from substituting the ARI-based manufacturer costs with those from the reverse engineering analysis. For all TSLs, there are a greater number of shipments forecasted under the reverse engineering manufacturer cost scenario. Because the reverse engineering manufacturer cost estimates are lower than those from ARI, there is less of an increase in central air conditioner and heat pump purchase prices. Thus, fewer consumers forego an equipment purchase.

Table 6.2 Shipments Impact from Reverse Engineering Manufacturer Cost Scenario

Year	Percentage Change from Shipments Forecasts based on ARI Manufacturer Costs					
	Base Case	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
2000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2001	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2002	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2003	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2004	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2005	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2006	0.0%	0.3%	0.9%	1.2%	2.8%	6.8%
2007	0.0%	0.3%	0.8%	1.1%	2.4%	6.6%
2008	0.0%	0.3%	0.8%	1.0%	2.1%	6.3%
2009	0.0%	0.3%	0.8%	1.0%	1.8%	6.1%
2010	0.0%	0.3%	0.7%	0.9%	1.5%	5.7%
2011	0.0%	0.3%	0.7%	0.9%	1.5%	5.6%
2012	0.0%	0.3%	0.7%	0.9%	1.4%	5.3%
2013	0.0%	0.2%	0.6%	0.8%	1.3%	5.0%
2014	0.0%	0.2%	0.6%	0.8%	1.3%	4.8%
2015	0.0%	0.2%	0.6%	0.8%	1.3%	4.6%
2016	0.0%	0.2%	0.6%	0.7%	1.2%	4.3%
2017	0.0%	0.2%	0.6%	0.7%	1.2%	3.8%
2018	0.0%	0.2%	0.5%	0.7%	1.2%	3.0%
2019	0.0%	0.2%	0.5%	0.7%	1.2%	2.5%
2020	0.0%	0.2%	0.5%	0.7%	1.2%	2.0%
2021	0.0%	0.2%	0.5%	0.7%	1.2%	1.7%
2022	0.0%	0.2%	0.5%	0.7%	1.2%	1.5%
2023	0.0%	0.2%	0.5%	0.7%	1.2%	1.5%
2024	0.0%	0.2%	0.5%	0.7%	1.2%	1.7%
2025	0.0%	0.2%	0.5%	0.7%	1.2%	1.8%
2026	0.0%	0.2%	0.5%	0.7%	1.2%	2.0%
2027	0.0%	0.2%	0.5%	0.7%	1.2%	2.2%
2028	0.0%	0.2%	0.5%	0.7%	1.2%	2.3%
2029	0.0%	0.2%	0.5%	0.7%	1.3%	2.6%
2030	0.0%	0.2%	0.6%	0.7%	1.3%	2.9%

6.4.3.2 Lifetime Scenario

The lifetime scenario is based on a retirement function yielding an average lifetime of 14 years in which no compressor replacement occurs. The shorter lifetime is based on the assumption that most, if not all, consumers when faced with replacing a failed compressor would choose to replace the entire system rather than replace the compressor in a relatively old system. Table 6.3 shows the percentage change in the annual shipment forecasts based on the use of a 14-year average lifetime retirement function. For all TSLs as well as the base case, there are greater number of shipments forecasted. Because units are being retired earlier (14 years on average versus 18 years), more shipments are forecasted.

Table 6.3 Shipments Impact from 14-year Average Lifetime Scenario

	Percentage Change from Shipments Forecasts based on ARI Manufacturer Costs					
Year	**Base Case**	**TSL 1**	**TSL 2**	**TSL 3**	**TSL 4**	**TSL 5**
2000	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%
2001	5.8%	5.8%	5.8%	5.8%	5.8%	5.8%
2002	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%
2003	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
2004	7.8%	7.8%	7.8%	7.8%	7.8%	7.8%
2005	7.8%	7.8%	7.8%	7.8%	7.8%	7.8%
2006	7.7%	8.0%	8.3%	8.5%	9.8%	17.0%
2007	7.3%	7.6%	7.9%	8.1%	9.1%	16.2%
2008	7.1%	7.5%	7.8%	8.0%	8.8%	15.6%
2009	7.5%	7.9%	8.3%	8.4%	9.0%	15.6%
2010	8.1%	8.4%	8.8%	8.9%	9.4%	15.3%
2011	9.0%	9.4%	9.8%	9.9%	10.3%	16.0%
2012	9.6%	9.9%	10.3%	10.4%	10.8%	15.8%
2013	9.7%	10.0%	10.3%	10.4%	10.8%	15.0%
2014	9.5%	9.8%	10.1%	10.2%	10.5%	13.9%
2015	9.4%	9.7%	9.9%	10.0%	10.3%	13.0%
2016	9.4%	9.6%	9.8%	9.9%	10.1%	12.0%
2017	9.1%	9.3%	9.5%	9.6%	9.8%	11.0%
2018	8.5%	8.7%	8.9%	8.9%	9.1%	9.5%
2019	8.2%	8.3%	8.5%	8.5%	8.7%	8.5%
2020	8.1%	8.2%	8.3%	8.3%	8.5%	7.8%
2021	8.0%	8.1%	8.2%	8.2%	8.3%	7.2%
2022	7.9%	8.0%	8.0%	8.1%	8.1%	6.7%
2023	8.0%	8.1%	8.1%	8.1%	8.1%	6.7%
2024	8.1%	8.2%	8.2%	8.2%	8.1%	6.7%
2025	8.2%	8.2%	8.1%	8.1%	8.1%	6.7%
2026	8.1%	8.1%	8.1%	8.1%	8.1%	7.1%
2027	8.0%	8.0%	8.0%	8.0%	8.0%	7.3%
2028	7.8%	7.9%	7.9%	7.9%	8.0%	7.6%
2029	7.7%	7.8%	7.9%	7.9%	8.0%	8.1%
2030	7.7%	7.8%	7.9%	7.9%	8.1%	8.7%

6.4.4 Sales and Shipments Impacts of Efficiency-Induced Price Changes

Figures 6.16 through 6.19 show the impacts relative to existing minimum efficiency equipment (i.e., 10 SEER) on forecasted equipment sales and shipments due to different efficiency levels (i.e., 11 through 13 SEER and 18 SEER) by product class under the NAECA *efficiency scenario* and *AEO2000* Reference Case. To note, the Shipments Model forecasts equipment sales in millions of dollars while shipments are forecasted in millions of units. Results are not shown by Trial Standard Level as each of the product classes are affected differently by changes in efficiency. In the figures, both the impacts at the year the efficiency level is assumed to become effective (2006) and the average impacts over the forecast period (2006 to 2030) are illustrated. For all classes, sales and shipment impacts for the 11 SEER efficiency level are well within 5% of the base case. For both HP classes, sales and shipment impacts for the 12 SEER efficiency level are also within 5% of the base case. Larger sales and shipments impacts are forecast for all other efficiency levels.

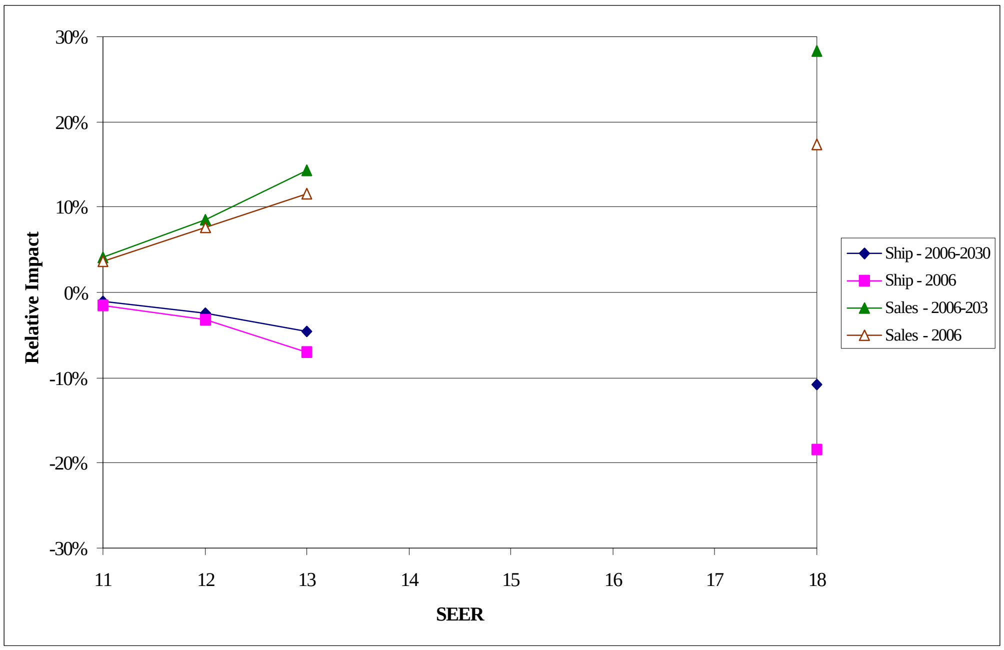

Figure 6.16 Impacts of Increased Efficiency for the year 2006 and Average Impacts over the period 2006 to 2030 for Split A/C Sales and Shipments

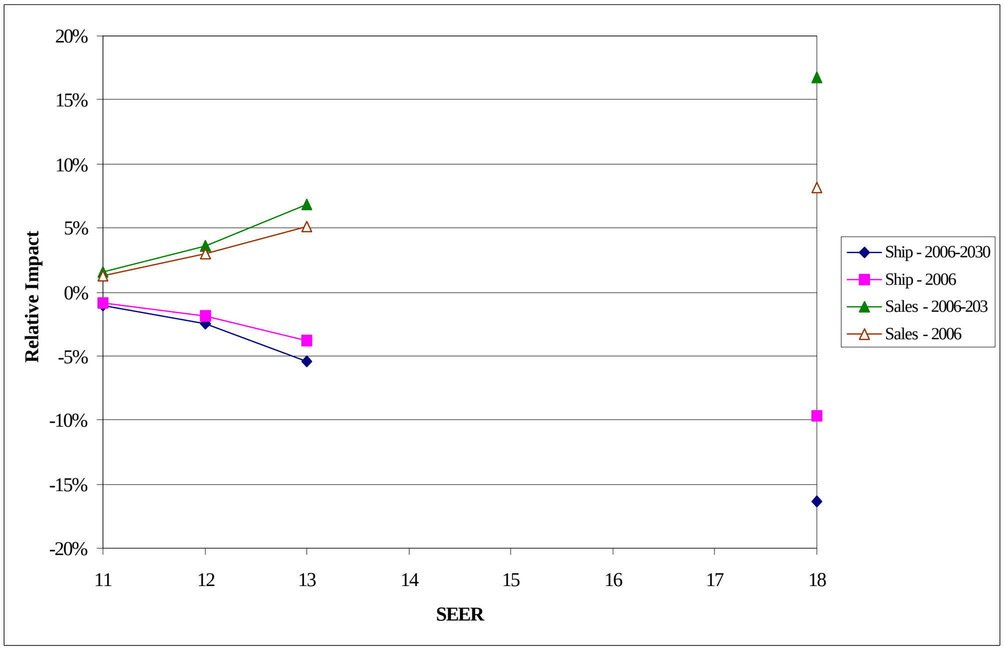

Figure 6.17 Impacts of Increased Efficiency for the year 2006 and Average Impacts over the period 2006 to 2030 for Split Heat Pump Sales and Shipments

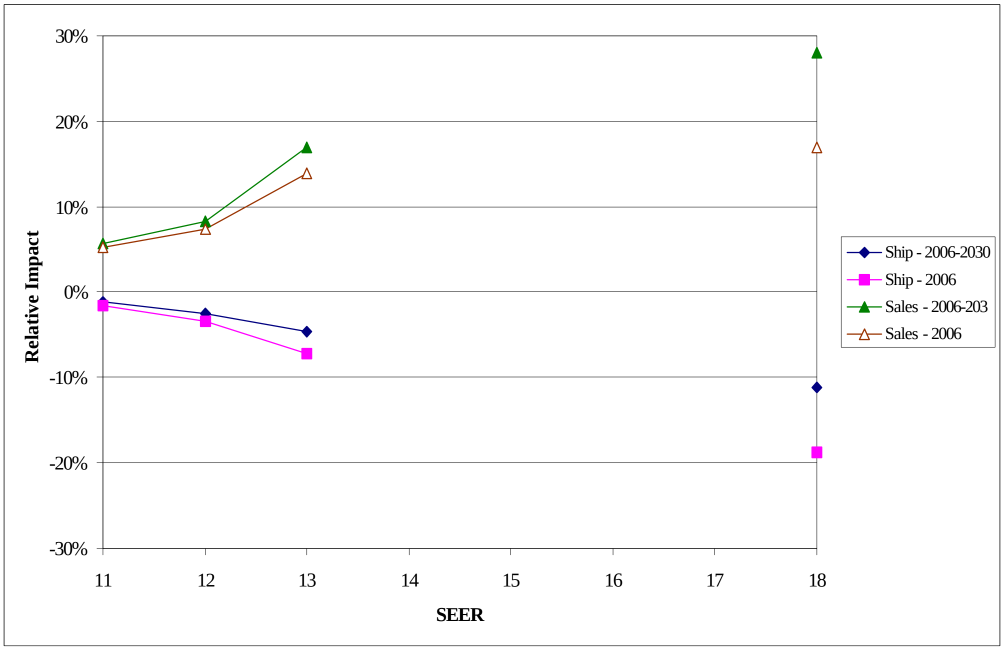

Figure 6.18 Impacts of Increased Efficiency for the year 2006 and Average Impacts over the period 2006 to 2030 for Package A/C Sales and Shipments

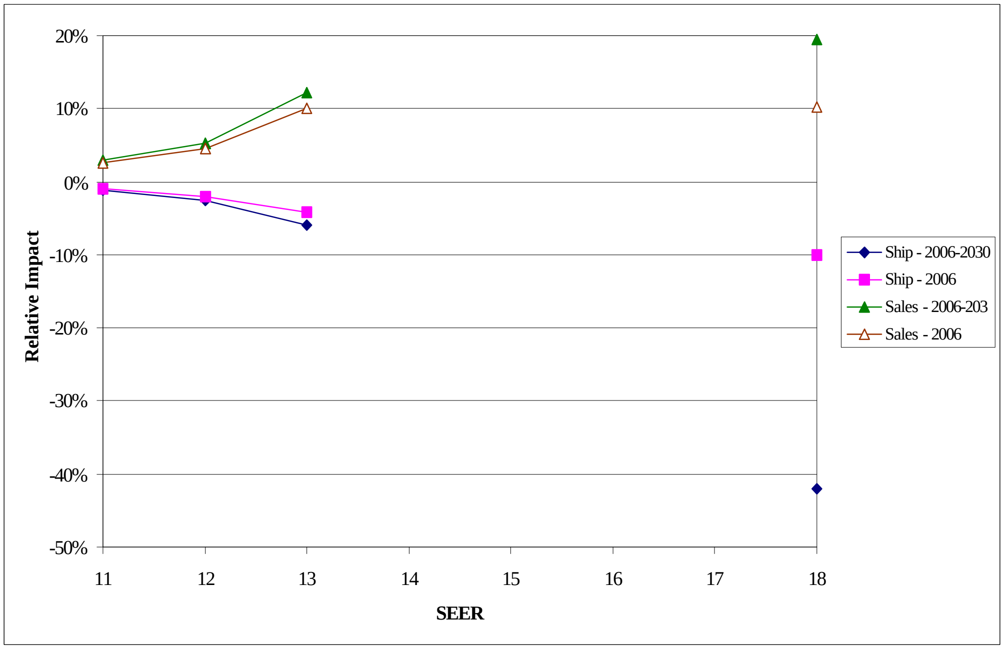

Figure 6.19 Impacts of Increased Efficiency for the year 2006 and Average Impacts over the period 2006 to 2030 for Package Heat Pump Sales and Shipments

The biggest factor that influences the size of the potential standards-induced changes is the actual installed consumer price increase that is induced by the standard. If price increases are large, the shipments volume decreases almost proportional to the price increase, but because the price elasticity is less than one, price increases result in increased gross sales dollar volume. The net financial impact of these opposing effects is examined in more detail in the manufacturing impact analysis (Chapter 8).

Some of the measures that consumers might take to avoid the purchase of a new higher-priced CAC-HP keep them out of the market for only a relatively short period of time. Therefore there is some recovery from the initial shipments drop that might be seen in the year a new efficiency level first takes effect. It is forecasted that the long term average shipments drop is approximately 40% and 35% less for CAC and HP, respectively, than the drop which might be seen in the first year that the efficiency level takes effect.

6.4.5 Impacts on Mean Age, Mean Lifetime, Early Replacements, and Total Repairs of CAC-HP

Figures 6.20 through 6.23 illustrate the estimated relative impacts on the mean age of CAC-HP, the mean CAC-HP lifetime, the early replacement of CAC-HP, and the total volume of CAC-HP repairs. These are average impacts over the time period of 2006 to 2030. These four different measures of CAC-HP retention measure different types of consumer reactions to higher potential

CAC-HP prices. Impacts are shown by product class in the following figures and have determined only under the NAECA efficiency scenario and *AEO2000* Reference Case.

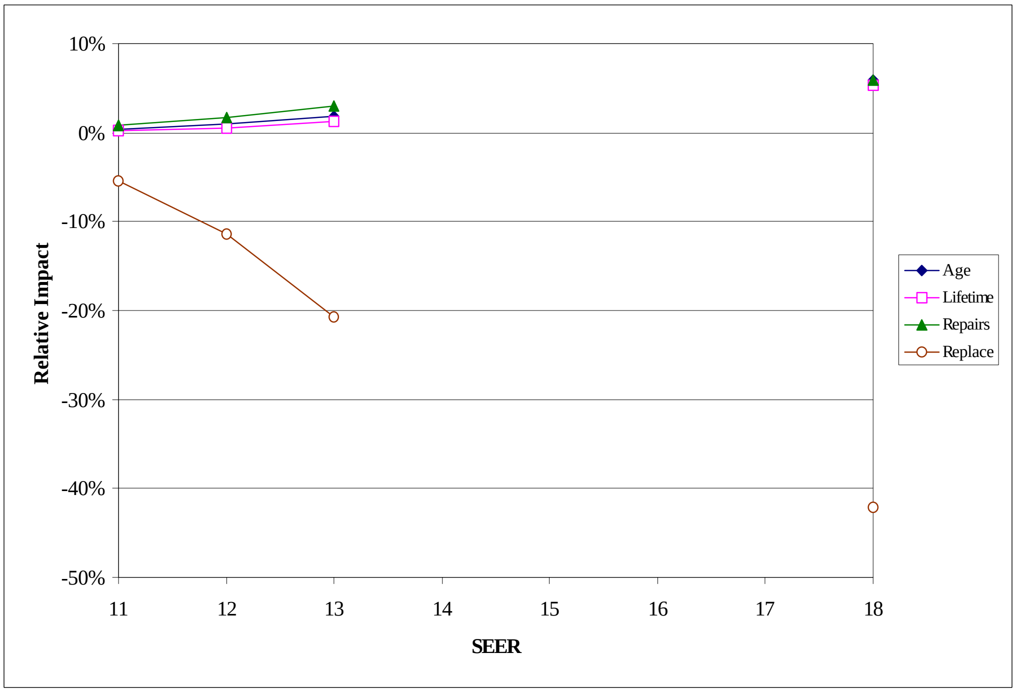

Figure 6.20 Average Impacts on Mean Age, Mean Lifetime, Early Replacements, and Total Repairs over the period 2006 to 2030 for Split A/C

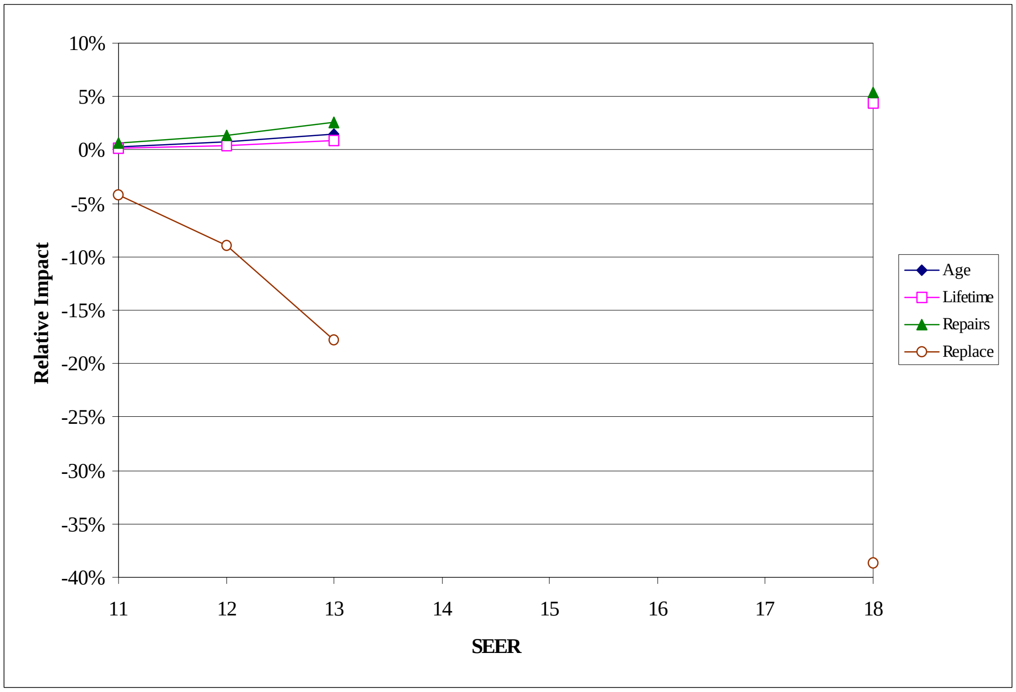

Figure 6.21 **Average Impacts on Mean Age, Mean Lifetime, Early Replacements, and Total Repairs over the period 2006 to 2030 for Split Heat Pumps**

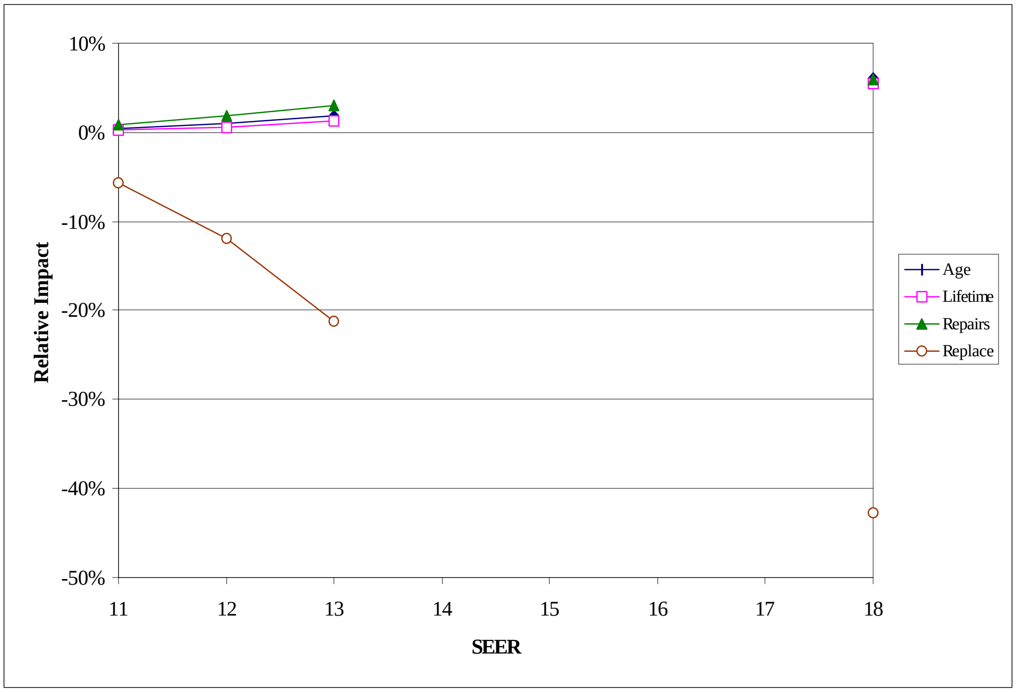

Figure 6.22 **Average Impacts on Mean Age, Mean Lifetime, Early Replacements, and Total Repairs over the period 2006 to 2030 for Package A/C**

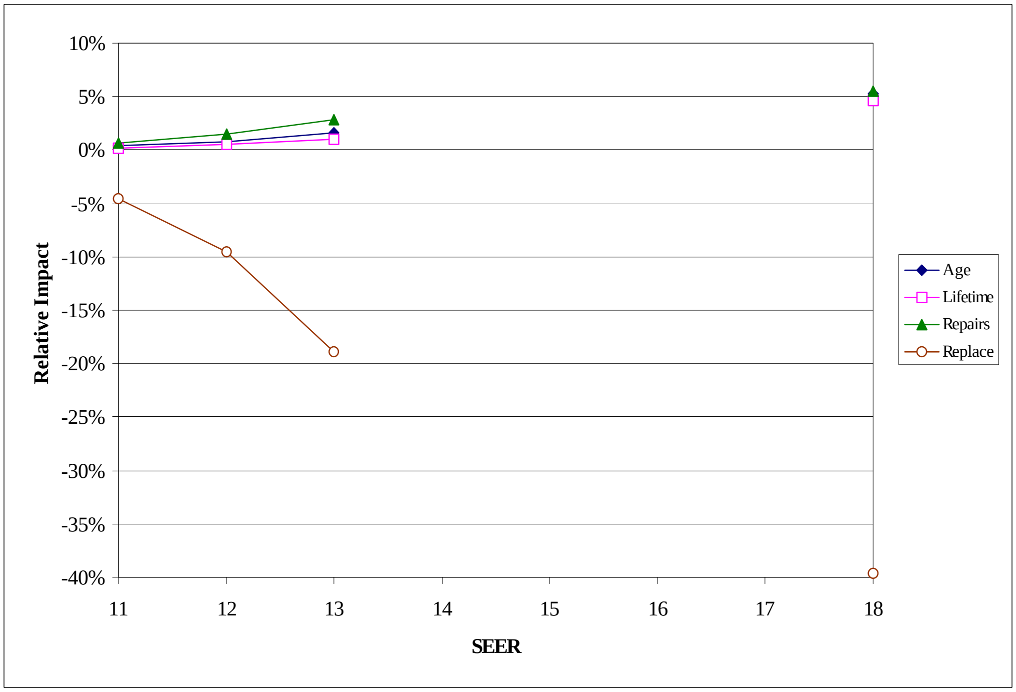

Figure 6.23 Average Impacts on Mean Age, Mean Lifetime, Early Replacements, and Total Repairs over the period 2006 to 2030 for Package Heat Pumps

The increase in repair rate measures the impact of consumers who perform an extra repair on their CAC-HP rather than retire the machine. As shown in Figures 6.20 through 6.23, such repairs increase with increased efficiency. This increase is primarily due to the corresponding decrease in consumers that replace their machines early.

The extended lifetime of CAC-HP reflects repairs that consumers might undertake to extend the lifetime of CAC-HP. Such extended repairs will have a delayed effect on the average lifetime of a CAC-HP, and only a relatively small fraction of machines will receive such extended repairs. An extra repair extends the life of a 18.4 year old machine by at most six years. The most significant impact of increased efficiency on lifetime is illustrated at the 18 SEER efficiency level. For example in Figure 6.20 for Split A/C, the 18 SEER efficiency level increases the mean lifetime by approximately 6% or just over one year.

The increase in mean age of a CAC-HP illustrates both the impacts of extra repairs and a decrease in consumers replacing their systems early. The proportion of older machines increases slightly, and this results in a slight increase in the average age of machines. Again, it takes several years for extra repairs to have a significant impact on the CAC-HP age distribution, so the averaged impact over the period is significantly smaller than the peak age increase which occurs several years after implementation of the standard.

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